M/035/009

BARNEYS CANYON MINE

WASTE ROCK MANAGEMENT PLAN

October 12, 1993

Revised on May 27, 1994

OST.100

M/035/009

State of Utah
DEPARTMENT OF ENVIRONMENTAL QUALITY
DIVISION OF WATER QUALITY

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Governor
Dianne R. Nielson, Ph.D.
Executive Director
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August 1, 1994

Mr. Dave Hodson
Barneys Canyon Mine
PO Box 311
Bingham Canyon, UT 84006-0311

Re: Waste Rock Management Plan,
Ground Water Discharge Permit
No. UGW350001

Dear Mr. Hodson:

We received your final proposal for the Waste Rock Management Plan, dated June 1, 1994. After review of the plan, and discussions on June 23, we are in general agreement with the proposed concepts and, subject to the following comments, you should proceed to implement the plan as rapidly as possible.

Any waste rock containing more than 0.5% sulfur must go to the specified waste dumps. This value appears reasonable as rocks containing more than this amount are easily identified in hand samples, and much of the remaining sulfur that is in rocks below this level is combined with barite and copper compounds that are not easily weathered.

The oxide waste dumps are to have a cap and soil cover that allows a vertical flow rate of about 0.4 inches per year. The pyritic dumps are to have a tighter cap and soil cover that allows less than 0.1 inches flow rate per year. The flow rate through the sulfide dumps will be considerably lower than the natural recharge rate used in models of the area. A low flow rate is a requirement because the amount of dissolved constituents in water percolating through the dumps will be much greater than under natural conditions. A statement should be added to the text referencing the Dames and Moore model that used 3 to 4 inches of recharge for the area and explaining this requirement. As discussed later we favor quality assurance/quality control (QA/QC) rather than a large monitoring program of the dumps.

The waste rock plan is tentatively approved subject to the submission for approval of more detailed maps, plans and drawings, as described below, for a modified ground water permit for the new pyritic Melco South dump, and the NBCS backfill pit.

Modifications to the permit are required because the dumps are considered new structures that are needed to protect water quality.

A. Pyritic Waste dumps and the backfill pit.

1. We need to review details of the cap, overall design, permeability, location, soil cover, and revegetation plans. Detailed drawings should be submitted for the Melco dump and the dump planned inside the NBCS pit. Also, what will be the water level in the NBCS pit and how will pit water be controlled during periods of high precipitation?

2. Figure 1 shows a drain at the base, your text does not describe the design, purpose, or use. If fluid, after a large precipitation event, exits at dump base, where will it go, what will be the quality and what is its spatial relation to the pyrite?

B. Design of monitoring lysimeters.

1. During the meeting you stated you favored QA/QC, over monitoring, inasmuch as 0.1 inch of flow through the pyritic dumps would probably not yield a measurable quantity. We agree a ground water monitoring mechanism for the dumps will not be necessary provided you submit an approvable QA/QC plan for the dump caps. You also stated you may try lysimeter monitoring of the oxide dumps. We would be interested in securing details for the monitoring plans and the results.

C. While the best coarse of action for the highwall sulfide is not readily apparent, information related to the surface area of the exposed sulfide, in the pits, would be helpful. However, we believe the various alternative suggestions for item 2,b - e in your report should be considered as best management practices under the permit and implemented as appropriate. The wording of the text should be revised.

D. We understand you are still evaluating a possible silicate highwall coating for the Barneys Canyon and the Melco pits. Please provide sufficient information, such as, compound name, composition and application rate so that we can determine that it will not have an adverse affect on the environment.

E. The proposed Melco South dump is not located on the map (site plan). The NBCS dump should also be labeled.

A revision of the recently submitted plan may be the simplest and quickest method to meet this request. Everything would then be under one cover.

We appreciate your efforts to make these changes to protect the downgradient water resources. You will also need to present the dump plans and changes to DOGM for their approval. Should you wish to discuss this request or need further clarification, please call Mack Croft or Lyle Stott at 538-6146.

Sincerely,

Utah Water Quality Board

Don A. Ostler

Don A. Ostler, P.E.
Executive Secretary

Enclosure

DAO:MGC:wfm:

cc: DOGM
Salt Lake City/County Health Department
Eva Hoffman EPA

P:DveHdsn.ltr
FILE:Barneys Canyon

We do have a general concern with the proposed location for the above referenced topsoil stockpile. As drawn on Plate II-C, it appears that it will be situated in the bottom of the Barneys Canyon drainage. A drainage bottom is usually not the best place to locate a topsoil stockpile due to the increased probability of erosional impacts. It is our recommendation that the stockpile be relocated out of the drainage profile to a higher elevation thereby minimizing topsoil losses due to water erosion.

R647-4-113 Surety

The surety section in the June 15, 1994 letter proposes a reclamation bond in the amount of **4.5** million dollars ($4,492,899 rounded). This figure is based on **1,061.9 acres** of disturbance multiplied by $4,231 per acre (1999-$). The reclamation cost estimate section in the updated draft NOI revision text proposes a reclamation bond of **4.6** million dollars ($4,535,209 rounded up) based on **1,071.9 acres** of disturbance at $4,231 per acre. The acreage difference between these two figures is 10 new acres of clay pit areas to be used during construction of new heap leach pads. A revised surety amount of $4,535,000 would satisfy the Division's bonding requirements; however, $4.6 million would also be acceptable. Please select one proposed surety amount. (AAG)

General Comments:

The Waste Rock Management Plan describes the conceptualized design plans for dump construction. One conceptual design cross section, Figure 1, Components of Dump Drainage, is provided in the plan. Under Section 4.2 and 4.3, verbal descriptions of the 'Oxide' and 'Sulfide' waste dump reclamation designs are provided. Please provide a conceptualized cross-section(s) of the sulfide dump design plans for the Melco South Sulfide dump and the NBCS pit backfill.

It is difficult to determine from the text, how (and where) the sulfide waste rock will be placed while the overall dump is being constructed. Will the sulfide waste rock be temporarily stockpiled and later moved to the final sulfide dump "repository" locations, or will it be immediately placed in the respective dump locations? How long will the sulfide bearing wastes be exposed to oxidation processes before they are ultimately covered/sealed? Please describe any interim protection measures proposed to minimize the potential for sulfide oxidation and acid or sulfate generation prior to final closure of these dumps?

Conceptual monitoring (lysimeters) and treatment plans for potential acid runoff (eg. pit walls) are proposed with finalized plans forthcoming at a future date. The Division agrees with the conceptual plans as outlined in this proposal. We will await future plans/revisions as they are developed. The State Division of Water Quality (DWQ) may require modifications to this proposal to demonstrate compliance with their Ground Water regulations. We would appreciate the opportunity to review any significant changes to this waste rock management plan that DWQ may require, before it is finalized and ultimately approved.

Your June 13, 1994 letter indicates that following issuance of our tentative approval decision, Kennecott will seek permission to begin road access construction, tree clearing, vegetation grubbing and topsoil removal activities. The decision to allow these preliminary development activities to occur will be an administrative call. Kennecott's posting of the revised Reclamation Contract (FORM MR-RC) and the amended surety amount will be of critical concern in the decision making process.

Thank you for your continued cooperation, time and patience in helping us complete this permitting action.

Sincerely,

Anthony A. Gallegos
for

D. Wayne Hedberg
Permit Supervisor
Minerals Regulatory Program

jb
cc: Kiran Bhayani, DWQ
Lowell Braxton, DOGM
Minerals file
M35-09rv.let

M/035/009

BARNEYS CANYON MINE
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FAX (801) 569-7190

David I Hodson
General Manager

Kennecott

JUN - 2 1994

June 1, 1994

Mr. Wayne Hedberg
Division of Oil, Gas & Mining
3 Triad Center, Suite 350
Salt Lake City, Utah 84180-1203

RE: Groundwater Discharge Permit No. UGW350001

Dear Mr. Hedberg:

Enclosed for your information is a copy of the final Barneys Canyon Mine - Waste Rock Management Plan (dated May 27, 1994) which has been submitted to the Division of Water Quality for approval under the terms of groundwater discharge permit No. UGW350001.

If you have any questions please contact me at telephone number 569-7200.

Yours sincerely,

D. I. Hodson
General Manager
Barneys Canyon Mine

enclosure

OST.100

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David I. Hodson
General Manager

Kennecott

June 1, 1993

Mr. Don A. Ostler
Division of Water Quality
Utah Department of Environmental Quality
288 North 1460 West
Salt Lake City, Utah 84116

JUN - 2 1994

RE: Groundwater Discharge Permit No. UGW350001

Dear Mr. Ostler:

Enclosed is our final proposal for the waste rock management plan as required under condition H3 of Groundwater Discharge Permit No. UGW350001.

This document has been extensively updated compared to our first submission dated October 12, 1993 and so supersedes that plan in its entirety.

In order to ensure a complete record of information supplied to you, consultants reports by Steffen, Robertson and Kirsten (SRK) which have previously been submitted to you, are also included in appendix 1 of the plan but they have not been revised.

The waste rock management plan is submitted for your approval and completes all requirements of the groundwater discharge permit.

Please address any questions to myself at telephone extension 569-7200 (fax 569-7190).

Yours sincerely,

D. I. Hodson
General Manager
Barneys Canyon Mine

cc: Mr. W. Hedberg / with attachment (DOGM)
C. S. Emmons

OST.100

CONTENTS

APPENDICES

1. ACID GENERATION POTENTIAL

The acid generation potential from the Barneys Canyon Mine waste dumps has already been reviewed by, Dr. Andrew Robertson of Steffen, Robertson & Kirsten (SRK) in a report which was submitted to DWQ on January 28, 1993. His report concluded that the potential for acid generation in the well blended rock piles which exist at Barneys Canyon, is very small. Subsequent analysis of the Melco and SBCS waste materials has again confirmed the low potential for acid generation as stated in SRK reports dated March 18, 1993 (SBCS) and April 15, 1993 (Melco) which are included here for reference in Appendix 1.

Since these reports were compiled Barite ($BaSO_4$) has been identified as a source of sulfur that reported as sulfide in the Melco samples. Barite is insoluble and non acid generating. The potential for acid generation at Melco has therefore been overstated. It is expected that if the barite were properly accounted, the ratio of neutralizing to acid generating material would favorably increase by a small amount. This would not make a significant difference to the rock waste disposal plan and so no further effort will be spent to evaluate the effect of the barite.

Petrographic studies have also determined that a significant portion of the sulfate material identified at the SBCS deposit occurs as a natural jarosite which is a relatively insoluble and unreactive sulfate species. The jarosite insolubility will give a greater margin of neutralizing potential over acid generation potential than stated in SRK reports but this would not significantly affect the waste rock dump design.

In any event the acid potential quoted in both the Melco and SBCS evaluation is considered to be conservatively high and thus the risk of acid generation can be considered extremely low.

2. FINAL PIT WALLS

At the end of the mine life there will be relatively small portions of sulfide waste exposed on the final pit walls at both Barneys Canyon and the Melco pits.

In the Barneys Canyon Pit sulfide is relatively unreactive, immediately buffered by the excess neutralizing capacity of the host rock and will in the course of time be submerged by water as the natural groundwater table is re-established. Once submerged the sulfide will not oxidize and thus will not be of concern.

At the Melco pit the sulfide will remain exposed and will rapidly oxidize. A very small quantity of acid runoff may occur during rainfall events at least until the exposed surface has fully oxidized.

Possible control alternatives considered are:

a) Apply a phosphate or silicate spray onto the sulfide to coat it and retard oxidation. The spray coat may last for 10-50 years but would not be permanent. (This could also be useful to prevent acid formation in the Barneys pit prior to it naturally filling with water which will effectively prevent long term oxidation.)

b) Collect highwall runoff and direct it away from the exposed sulfides.

c) Place neutralizing lime/limestone/phosphate on pit benches (in the sulfide zone) to neutralize runoff.

d) Place neutralizing rock in the pit bottom to neutralize runoff.

e) Create an infiltration zone to ensure runoff does not stand in contact with sulfides in the Melco pit bottom.

Further testing is required to determine the best course of action for the Melco pit.

3. SULFATE MOBILIZATION

Sulfate is a secondary concern which is evaluated in connection with mine drainage. As shown previously, the waste rock dumps throughout the Barneys Canyon project will either be neutral because of the balance between low acid generating and the high neutralizing materials or, as in the case of Barneys pit mine waste dumps, be generally of higher pH. Sulfate may be present in the Melco and South Barneys South waste dumps, but will not be present as an environmental contaminant because of its immobility within the system.

Sulfate mobilization is partially dependent upon chemical reactions within the dump and on infiltration of sufficient water to move the sulfate out of the dump. Oxidation of sulfide minerals to produce sulfates is limited by chemical kinetics within the system. Kinetic test data previously submitted shows that oxidation is slow if the material is sufficiently mixed with neutralizing material. With adequate mixing of waste materials, the dumps remain at neutral pH or slightly higher, thus reducing the solubility of sulfate within the system. The SRK reports include results of shake flask tests which show the net pH of the waste to be above 8, even if exposed to slightly acidic solutions. A neutral pH inhibits the dissolution of the sulfate minerals, limiting the ultimate concentration of sulfate in solutions.

A more important consideration in determining whether sulfate will be mobile in the waste dumps is the physical configuration of the dumps. The relative density, permeability of the dumps and underlying strata, evaporation rates and topography all affect the amount of infiltration of precipitation into the dumps and consequently the potential for exfiltration from the dump.

Figure 1 shows potential water flow paths in and around mine dumps. The waste dumps are all located well above the regional groundwater table, therefore the only potential transport mechanism is through precipitation and infiltration. At the Barneys Canyon Mine, infiltration of precipitation is very low, and that infiltration may not be evenly distributed within the dumps. This reduces the potential for dissolution of sulfates if they are present. Each of the flow paths are described below:

3.1 Precipitation/evaporation: The Barneys Canyon Mine is located in an arid area, with average annual rainfall of 16 inches. The site also experiences a high evaporation rate, which directly affects the amount of water available for infiltration. Evaporation of precipitation is not restricted to surface evaporation as water is retained in the upper surface of the dump and subsequently evaporated. Ultimately, at closure, vegetation cover will also enhance evapotranspiration.

3.2 Surface flows - Much of the precipitation on the dumps reports as surface runoff. During active use of the dump, the top is maintained flat to accommodate the vehicular traffic. The dump surface is compacted by normal traffic flow and road maintenance activities such that the surface permeability is reduced to about 5×10^{-5} cm/sec. Drainage ditches divert water as needed to prevent ponding. At closure, the top of the dump will be configured so that it slopes to diversion channels or to intercepting trenches or impoundments which allow water to drain directly into colluvium thus routing precipitation around the dump.

3.3 Preferential flow along contact - A water control mechanism in the dump design is drainage along the natural ground/dump interface. Drainage from above the dumps generally continues along the natural topography, entering the dump at the interface. Part of the management strategy will be to intercept this water and direct it around dumps where possible. In the naturally steep topography at Barneys Canyon, the water which is not redirected will preferentially flow along this interface without dispersing into the dump. This may result in short lived local washing of sulfates but because of the short contact time, concentrations would likely be moderate (up to 500 ppm SO_4). In a relatively short time, the exposed sulfates will be rinsed out of the interface zone resulting in background levels of sulfate concentration in the flow. why? not compaction?

3.4 Constructed benches and faces - During dump construction, the top is compacted and maintained for vehicular traffic. This compaction occurs as a result of continuous vehicle traffic and frequent grading to assure a flat, compacted bench. This compaction results in a low permeability material. Evaporation is enhanced because of the low permeability and runoff will be directed to the intercepting trenches described in (3.2) above.

3.5 Dump drain in an end-dumped waste pile - Large waste rocks preferentially segregate at the bottom of the pile. In the steep terrain of the Barneys Canyon Mine, the preferential segregation results in a French drain type system with very high permeability. This drain is continued with every advance of the dump face and serves as a collection system for water which may migrate through the dump. Slowly migrating solution may attain sulfate concentration of about 2,000 ppm if the flow path is long enough, however water flow in dumps tends to be along channels and so long contact paths are not expected. The exact concentration of sulfates will be controlled by the relative amounts of calcite or dolomite in contact with solution and by the contact time. It is believed that all of the waste dumps at Barneys Canyon will remain unsaturated and that solution released would be a very small volume because of low infiltration into the dump.

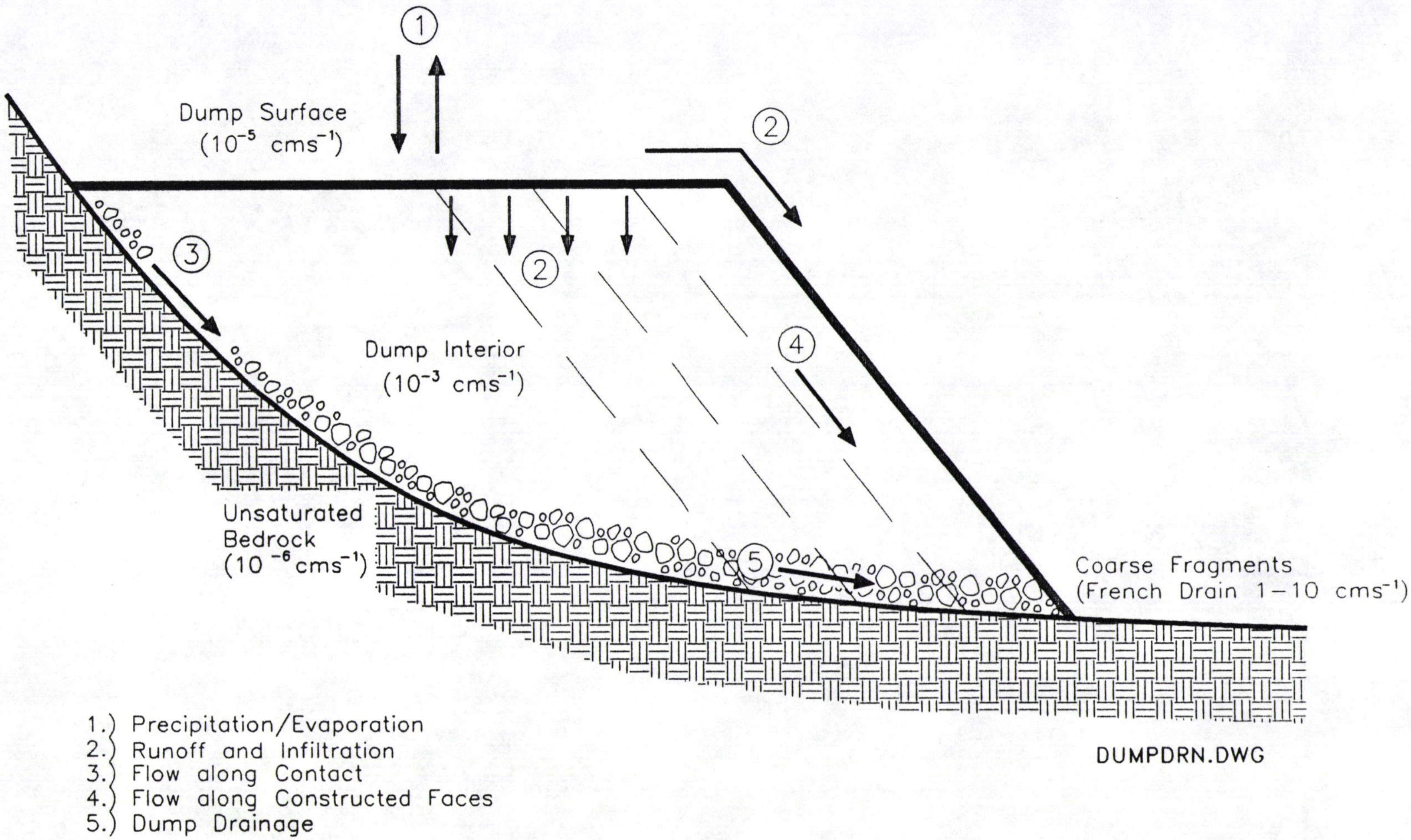


FIGURE 1

COMPONENTS OF DUMP DRAINAGE

4. ROCK WASTE DUMP DESIGN

4.1 Consideration of the water flow characteristics described in section 3 lead to the conclusion that the most important factor to control is the rate of infiltration of water through the dump surface.

With this in mind, consultants Water, Waste and Land, Inc. (WWL) were employed to carry out detailed analysis of the waste dump characteristics and to provide suitable dump designs that would minimize infiltration. The consultants were asked to evaluate waste dump configurations using on site materials that would minimize infiltration through a reclaimed and revegetated dump.

Ultimately two types of dump reclamation were designed:

The first type of reclamation will be for waste dumps containing oxide or low level sulfide material with abundant neutralizing potential. The second type of reclamation will be for selectively constructed dumps containing higher level sulfide material which will not have net neutralizing capacity.

In discussions held with DWQ, DOGM and consultants it was generally agreed that segregation of the waste rock with higher sulfide content into discrete piles was a better approach than mixing sulfides throughout much larger oxide waste dumps. Whilst the mixed rock approach ensures adequate neutral-izing potential it would mean that in the event that unsatisfactory discharge from the dump is detected (in the long term future) then remediation would be a major project. Segregation of the sulfides into smaller discrete piles increases the risk of acid generation but ensures that remediation (if required) can be a manageable project. In order for this approach to be secure environmentally, the infiltration rate for the sulfide waste piles would need to be lower than for the innocuous oxide waste dumps.

WWL utilized the HELP computer model to evaluate the most appropriate dump cover designs and then used the UNSAT2 model - which has more precise algorthims for modelling water flow and evapotranspiration than the HELP model - to confirm the results generated by the HELP program. A copy of the WWL study is included in Appendix 2.

In summary, the final waste dump relamation designs selected will be as follows:

4.2 'Oxide' Waste Dump Reclamation Design:

'Oxide' dumps containing minimal sulfide bearing material will require revegetation as originally planned. Modelling indicates that this plan will ensure infiltration of about 0.4 inches per year.

Upon completion of mining, the dumps will be recontoured and the dump surface will be sloped such that significant ponding of water on the surface will not occur. The upper 12 inches of the dump surface will be amended with topsoil and/or organic material such as sewage sludge or mulch which will be mixed into the rock surface by ripping with a dozer to a depth of at least 24 inches. The dump surface will be fertilized and reseeded with a selection of local plant species designed to create rapid vegetation growth with good leaf cover and a rooting zone of 24 inches depth. The detailed revegetation scheme is described in a report from Dr. D. Morrey of Golder Associates which is included as Appendix 3.

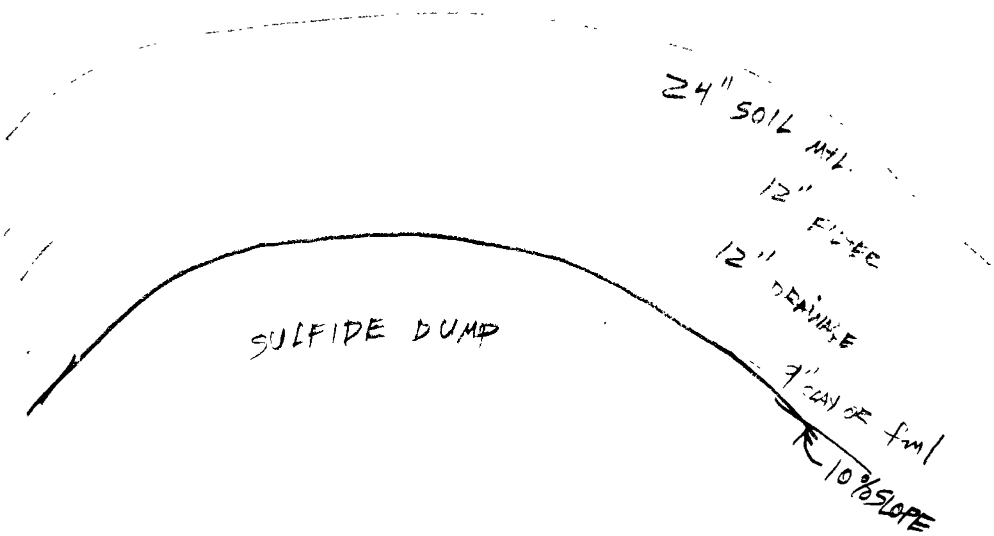
The expected average infiltration rate into the reclaimed dumps of 0.4 inches per year compares to a natural recharge rate in the Oquirrh range of 6-10 inches per year as reported by the State Department of Natural Resources. (Various reports by Hely (1971), Waddel (1981), Lambert (1993) and for Tooele by Razen and Steiger (1981) substantiate this estimate.)

The good quality of the rock material at the dumps will ensure that exfiltration from the dump contains no significant contaminants and the substantial dilution effect from natural recharge in the catchment will ensure that background groundwater quality does not change by more than the natural variations noted for the area.

The dumps reclaimed in this manner will be: The Barneys Canyon 6300 and 6500 dumps, the SBCS dump, Melco 7200, 7300 and 7460 dumps and the Melco North dumps.

4.3 'Sulfide' Waste Dump Reclamation Design:

All waste rock containing more than 0.5% sulfur as sulfide will be separately stockpiled in two designated dumps, the Melco South Sulfide dump and the NBCS pit backfill.


24" SOIL MTL.
12" FILTER
12" DRAINAGE
SULFIDE DUMP
10% SLOPE

In these dumps the sulfide bearing waste will be constructed to minimize the likelihood of dump settling.

Upon completion of the dump, the surface will be graded to a slope of at least 10% and covered with a barrier layer which has permeability of approximately 10^{-8} cm/sec. The barrier layer could consist of 9 inches of compacted clay or a flexible membrane liner depending on the economic availability of suitable materials.

The barrier layer will be covered by a 12 inches layer of good draining material such as coarse sand which will promote lateral drainage of water reaching that layer. The drainage layer will be protected by a filter blanket of graded material at least 12 inches thick. This will minimize migration of fines into the drainage layer and also act as a barrier to plant root penetration into the clay. On top of the filter blanket will be at least 24 inches of growth medium (consisting of organically amended waste rock with topsoil) which will be revegetated in accordance with Dr. Morrey's recommendations.

A cover of this type will limit percolation into the dump to less than 0.1 inch per year.

4.4 Management Controls

The following practices will be adopted to ensure that potential for ground water impact is minimal:

i. From the Melco pit, segregate sulfide bearing waste of more than 0.5% sulfide sulfur content and deposit it into one of the two designated sulfide dumps.

ii. Waste containing less than 0.5% sulfide sulfur will be mixed with oxidized waste in the oxide waste dumps and will be covered by at least four feet of clean oxide waste.

iii. Dump surfaces will be contoured to promote sheet run off with minimal erosion and no significant ponding of water. Runoff will be directed back into natural drainages via sediment control structures or will be allowed to reinfiltrate into the natural surface at selected points where the dumps contact the natural ground contour.

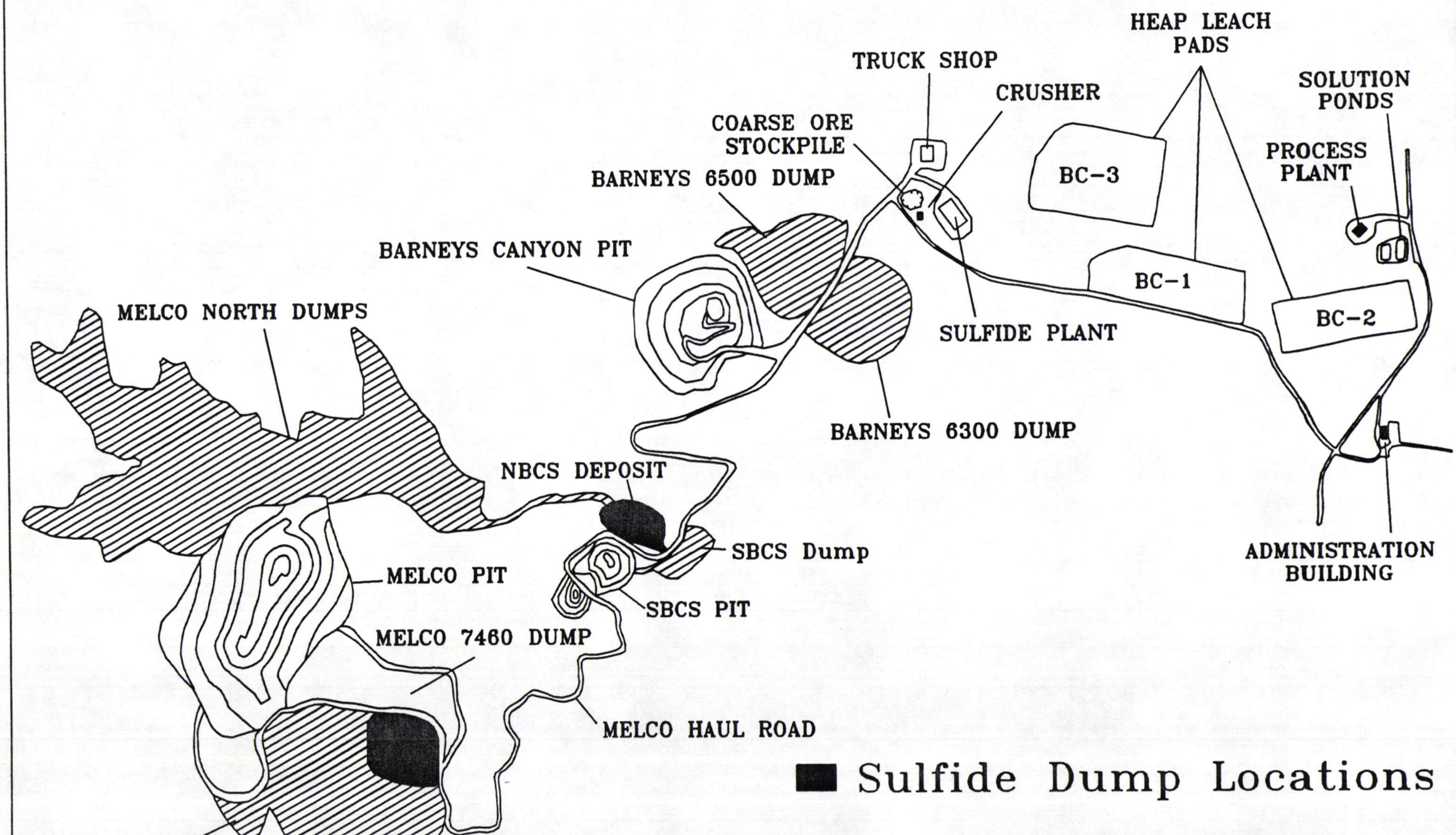
iv. Finished dumps will be topsoiled and revegetated in accordance with the mine reclamation plan.

v. Two lysimeters will be constructed in order to try and demonstrate that the low levels of dump infiltration expected, do in fact occur.

One lysimeter will be placed in either the Barneys 6300 or the SBCS dump and another in either the Melco 7200 or Melco North dump. The exact locations will be selected at the time of reclamation to ensure proper access is available and that the position chosen will give results representative of the whole dump area. As noted in the study by WWL the use of a lysimeter is likely to be the best method of monitoring performance but cannot be guaranteed to give meaningful results over a time period of even a few years. At best Lysimeters will only indicate gross errors in the modelling exercise. Results, even over a long time scale (10+ years), will have to be interpreted with caution.

vi. A process plant is expected to be commissioned in September 1994 which will treat sulfide rock which contains gold in economic quantities. Efforts will be sustained towards treating the maximum economically feasible quantity of sulfide material in this plant. This will minimize the quantity of sulfide material reporting to the waste dumps.

vii. The quantity of sulfide material exposed in the final pit walls will be estimated and field trials will continue to determine the best method of controlling potential acid runoff from the pit walls as described in section 2 of this plan.


HEAP LEACH PADS
TRUCK SHOP
CRUSHER
SOLUTION PONDS
COARSE ORE STOCKPILE
PROCESS PLANT
BARNEYS 6500 DUMP
BC-3
BARNEYS CANYON PIT
BC-1
BC-2
MELCO NORTH DUMPS
SULFIDE PLANT
BARNEYS 6300 DUMP
NBCS DEPOSIT
SBCS Dump
ADMINISTRATION BUILDING
MELCO PIT
SBCS PIT
MELCO 7460 DUMP
MELCO HAUL ROAD
Sulfide Dump Locations
MELCO 7300 DUMP
MELCO 7200 DUMP

SITE PLAN

STEFFEN, ROBERTSON AND KIRSTEN (CANADA) INC. Consulting Engineers
Suite 800, 580 Hornby Street, Vancouver, B C Canada V6C 3B6
Phone (604) 681-4196 Fax (604) 687-5532

RECEIVED
FEB 4 1993

January 15, 1993
Project Number S113101,

Kennecott Corporation, SLC
Barneys Canyon Mine
P.O. Box 311
8200 South 9600 West
Bingham Canyon, Utah
84006-0311

Attention: Mr. D. Hodson, Mine Manager

RE: ARD TEST RESULTS FROM THE BARNEYS CANYON AND MELCO DEPOSITS

This letter presents a summary of the test results and the interpretation used to evaluate the potential for acid generation of rock samples collected in the Barneys Canyon Pit, the Melco Pit, and the South Barneys Canyon Pits. The testing was done in two phases consisting of a static testing program on samples from the 4 pits, and kinetic testing on selected samples that were classified as having a marginal potential to generate acid. Most of the static test results were summarized previously in Kennecott's "Notice of Intention to Revise Mining Operations, Barneys Canyon Project" dated October 1, 1992. Some additional analyses of sulfur species have been recently compiled and are reported herein.

All the test data we have reviewed was generated by Core Laboratories in Denver.

Static Test Program

For the acid base accounting tests, standard procedures, based on the documented EPA test procedure (Sobek *et al.*, 1978) were used. As the standard procedure does not take into consideration non-sulfide species in the calculation of AP, a selection of samples from the South Barneys Canyon Pits were tested for sulfur speciation to refine the results.

Acid base account tests are used to define the balance between potentially acid generating minerals (sulfides) and potentially acid consuming minerals (typically carbonates) in a sample. Theoretically a sample will only generate acidic leachate if the potential for acid generation (AP) exceeds the neutralization potential, (NP) or has a NP/AP ratio of less than 1. However, in a rock pile, the physical distribution of the potentially acid generating and acid neutralizing minerals may be sufficiently variable that acidic seeps may develop for NP/AP ratios greater than 1. For mine rock piles, it is generally accepted that samples with an NP/AP of less than 3:1 (but greater than 1) there is still uncertainty as to the potential for acid generation. It is our opinion that where the sulfide and base mineralization is disseminated fairly uniformly in the rock mass (as is the case at Barneys Canyon) and is not concentrated on joints, that this ratio can be reduced to 2:1. An additional index based on NNP is also used, where samples in the range of +20 to -20 kg $CaCO_3$ equivalent/tonne are in this uncertain range. If a sample falls within the uncertain range, kinetic testing is generally required to determine the likelihood for contaminant release and acid generation. In addition, where sulfide sulfur is low (generally less than 0.05%) it is considered that the potential for acid generation is insignificant, even if no NP is available.

The test results have been compiled and are presented by pit area in Appendix A, Tables A1 to A4. Please note that the data is discussed and presented as a net neutralization potential (NNP) rather than a net acid generation potential (AGP) and a ratio of NP/AP is used in the assessment.

Barneys Canyon Deposit

A temporary sulfide stockpile and a mine waste dump are being developed. The rock being placed in the waste dump can be classified as either oxide or sulfide waste and is clearly distinguishable by its color. Estimates provided by the Barneys Canyon mine personnel are that the oxide waste represents over 95% of the waste produced in the pit.

Six samples, consisting of 3 oxide waste rock samples from the pit, and 3 sulfide rock samples from the temporary sulfide stockpile, were collected from the Barneys Canyon pit.

Two of the three sulfide waste samples were clearly acid consuming, with NP/AP ratios of greater than 3:1. The third sample, was in the range where the potential to generate acid cannot be determined by static tests alone. This sample has an NP/AP ratio of 1.3:1. The total sulfur content of these samples ranged from 1.1 to 1.7 percent. However any acid generation potential is balanced by a very high neutralization potential for all the samples tested, in the range of 69 to 249 kg $CaCO_3$ equivalent/tonne. The nature of the host rocks (dolomitic and calcareous sediments), explains the high NP measured in these samples. These samples indicate that two thirds of the sulfide waste is strongly acid consuming and one third has a low to moderate potential to generate acidity over the long term. When well blended in the temporary sulfide stockpile, such a mixture will not be acid generating, over the period (a few years) that the temporary sulfide stockpile will be maintained.

The oxide waste samples were all clearly acid consuming, with NP/AP ratios greatly exceeding the recommended 3:1 ratio. Two of the samples contained an insignificant amount of sulfur and therefore have little potential to oxidize, the third sample contained 1.2 percent sulfur. The neutralization potentials for all the samples were very high, ranging from 212 to 235 kg $CaCO_3$ equivalent/tonne. These samples indicate that this material is strongly acid consuming.

The sulfide waste contained in the waste dump represents less than 5 percent of all waste. With such a small portion of mainly acid consuming sulfide waste evenly distributed within such strongly acid consuming oxide waste, the blend will be non-acid generating.

Melco Deposit

The existing temporary sulfide stockpile and mine waste dump will be expanded by additional mining. Barneys Canyon mine personnel have indicated that the sulfide waste represents less than 5 percent of the total waste that will be produced.

Twelve samples, consisting of 6 sulfide samples from the temporary sulfide stockpile and 6 oxide samples from the pit were collected from the Melco deposit.

All of the Melco sulfide samples are clearly acid generating, based on total sulfur contents. Sulfur speciation was not done on these samples. It is however expected that the samples would still be net acid generating even if a significant portion of the sulfur is present as sulfate (non-reactive form), as only one of the samples contained a measurable neutralization potential. Based on the geologic information available to us, it is not surprising that the sulfide bearing rocks at the Melco mine site are barren of NP. Along with the mineralization, alteration of the host rocks as reported by mine geologists consist of a decalcification, or replacement of carbonate minerals by other unspecified minerals. This alteration was not noted in the oxide rock.

The temporary sulfide stockpile will be acid generating and will require acid rock drainage control measures, as presently agreed with the Division of Water Quality, to prevent either generation or migration of contaminated drainage.

Four of the oxide samples had significant neutralization potentials, in the range of 23 to 85 kg $CaCO_3$ equivalent/tonne. Two oxide samples had low neutralization potentials, with values of 0.6 and 4.2 kg $CaCO_3$ equivalent/tonne respectively. The total sulfur content was however low for all the samples tested, with sulfur values ranging between 0.01 and 0.22 percent. Five of the 6 samples were clearly acid consuming, with NP/AP ratios of greater than 6.7:1. The remaining sample is classified as a net acid generator, based on the total sulfur content. It is however likely that some of this sulfur is present as sulfate and therefore not available to oxidize and generate acid and therefore at the relatively low total sulfur content, a reclassification of this sample may be possible. Sulfur speciation was not conducted on this sample.

These samples indicate that a well blended waste dump with less than 5 percent sulfides will not generate acidic drainage. It is recommended that additional samples be taken to confirm the spatial distribution and proportions of the waste types.

South Barneys Canyon - North Deposit

A waste dump will be developed for the mine waste from this deposit. A total of 19 samples from the South Barneys Canyon, North Deposit were tested.

The total sulfur content of all the samples tested was very low, typically in the range of 0.01 to 0.03 percent, with one sample with a value of 0.11 percent. A sulfur speciation test done on the sample with the highest sulfur content indicated that all the sulfur was present as sulfide. The neutralization potential of the samples varied significantly, with values ranging from 0 to 981 kg $CaCO_3$ equivalent/tonne reflecting the sandstone or dolomitic host rock. The median NP was 14.5 kg $CaCO_3$ equivalent/tonne. High values were consistently measured for samples classified as dolomite. Only two of the samples could not be classified as net acid consumers. Of these one sample was barren of both sulfur and NP, and the other was in the range where the potential for acid generation could not be conclusively determined using static tests. Considering the low sulfur content and appreciable acid consuming capacity it is concluded that a well blended waste rock from this deposit would not be acid generating.

South Barneys Canyon - South Deposit

A waste dump will be developed for this open pit. A total of 29 samples from the South Barneys Canyon, South Deposit were tested.

One sample was classified as sulfide waste rock and was clearly acid generating with an NNP of -273.4 kg $CaCO_3$ equivalent/tonne. Barneys Canyon mine personnel have reported that about 0.1 percent of all the rock to be produced will be similar to this sample.

Both the neutralization capacity and the sulfur content varied substantially in the remaining samples, (28)
indicating a mixture of acid generating, marginal or uncertain, and acid consuming rocks. Of the
remaining samples tested, 6 were potentially acid generating with sulfide (or total sulfur where speciation 6/28
was not done) contents ranging from 0.10 to 0.45 percent and 5 are considered to be marginally potentially 5/28
acid generating based on sulfide contents of 0.05 to 0.1 percent. Generally the sulfate levels were very
low. However, for three of the samples a significant portion of the sulfur had been oxidized to sulfate, 3/28
suggesting that acid potential estimates, based on the total sulfur content, may overestimate the actual acid generation potential. The neutralization potential measured in potentially acid generating samples was typically low, ranging from 0 to 5.2 kg $CaCO_3$ equivalent/tonne.

Eight of the samples tested are in the range where the potential for acid generation could not be reliably concluded from the static test results. Of these, three samples are barren of sulfur and of NP, and are therefore unlikely to produce acidity regardless of the reaction kinetics.

Nine of the samples are acid consuming, with NP/AP ratios of considerably greater than 3:1. The total sulfur content was low for all these samples, ranging from <0.01 to 0.08. The NP levels were moderate, ranging from 6.4 to 40.4 kg $CaCO_3$ equivalent/tonne. According to the geologic map of the area, the host rocks contain less carbonate mineral content than the major host rocks in the North Deposit, explaining the overall lower neutralization capacity measured in this deposit.

An acid base accounting of all the waste samples indicates that there is a net acid consuming capacity with the ratio of NP/AP for all samples being 2.3:1. To ensure that the acid consuming waste is available where acid generation potential exists will require appropriate distribution and mixing of the waste rock on the waste dump.

BCS DUMP

Kinetic Testing Program

Kinetic tests (humidity cell tests) were done on four of the samples from the South and North Deposits for which the static testing results were inconclusive. The humidity cell data is provided in tabular form in Appendix B. The test cells did not develop acidic drainage. While these results do not indicate acid generation it is recommended that additional larger scale tests be performed with material of larger particle size. These tests will aid in the development of appropriate waste dumping methods.

In Summary

The geochemistry of the temporary sulfide stockpiles and waste rock from the 4 mining areas were reviewed: the existing Barneys Canyon and Melco pits, and the proposed Barneys Canyon South, North and South Deposits. The geochemical characteristics for each of the mining areas are quite different, dependant largely on the calcarious content of the host rock. Sulfide mineralization occurs mainly in the 'sulfide' rock and is generally very low in all 'oxide' rocks which are clearly distinguishable according to color. The sulfide rocks represent less than 5 percent of all waste from any one pit.

For the **Barneys Canyon deposit**, the sulfide deposit is hosted primarily in high calcareous rocks and the mine waste is highly acid consuming. The sulfide rocks are also net acid consuming though one sample was marginal. With only a small proportion (less than 5 percent) of sulfide waste distributed through the highly acid consuming oxide waste, the waste dump will not be acid generating. The available test data indicates that the temporary sulfide stockpile has a low acid generation potential and that there is sufficient alkalinity to prevent acidic drainage in the short term, i.e. for a few years prior to milling.

The **Melco deposit** is hosted in rocks with a moderate to high acid consumptive capacity and sulfide mineralization is generally low in the oxide waste. With only a small proportion (less than 5 percent) of sulfide waste distributed and blended through the moderate to high acid consuming oxide waste, the waste dump will not be acid generating. Additional sampling for static testing is recommended to confirm the spatial distribution and proportions of the waste types. The temporary sulfide stockpile will be acid generating and control measures are required, as agreed with the Division of Water Quality, to prevent acid generation or migration of contaminated drainage.

Representative samples from the **Barneys Canyon South, North Deposit**; indicated that the waste rock did not have an appreciable sulfide content. With the moderate to very high neutralization potentials measured for these wastes the waste dump will not be acid generating.

Samples from the **South Barneys Canyon, South Deposit**; indicate a ratio of acid consuming to acid generating minerals of 2.3:1. At this ratio, and using appropriate dump development and waste blending practices, a non-acid generating dump can be developed. Additional evaluation and testing is recommended to assist in the definition of the appropriate dump development.

Yours truly,

STEFFEN ROBERTSON AND KIRSTEN (CANADA) INC.

Dr. A. MacG. Robertson, P.Eng.
Principal

AMR/073

TABLE 1
Barneys Canyon Mine, Static Testing Data

Sample ID	Sulphur (S)T	Sulphate (SO4)	Sulphide (S)	AP*	NP*	NNP*	NP/AP	Notes
BCSS-1	1.7	NA	NA	53.1	68.9	15.8	1.30	Sulphide
BCSS-3	1.55	NA	NA	48.4	249.0	200.6	5.14	Sulphide
BCSS-2	1.07	NA	NA	33.4	111.0	77.6	3.32	Sulphide
BCOX-3	1.16	NA	NA	36.3	235.0	198.8	6.48	Oxide
BCOX-2	0.03	NA	NA	0.9	212.0	211.1	226	Oxide
BCOX-1	<0.01	NA	NA	0.0	232.0	232.0	232	Oxide

Note * (kg CaCO3 equivalent/tonne)

TABLE 2
Melco Mine, Static Testing Data

Sample ID	Sulphur (S)T	Sulphate (SO4)	Sulphide (S)	AP*	NP*	NNP*	NP/AP	Notes
MCS-2	5.15	NA	NA	160.9	<0.1	-160.9	0.00	Sulphide
MSS-2	5.14	NA	NA	160.6	<0.1	-160.6	0.00	Sulphide
MSS-1	2.88	NA	NA	90.0	<0.1	-90.0	0.00	Sulphide
MCS-3	2.37	NA	NA	74.1	<0.1	-74.1	0.00	Sulphide
MCS-1	1.52	NA	NA	47.5	<0.1	-47.5	0.00	Sulphide
MSS-3	0.85	NA	NA	26.6	17.4	-9.2	0.66	Sulphide
MCOX-2	0.22	NA	NA	6.9	0.6	-6.3	0.09	Oxide
MCOX-1	0.09	NA	NA	2.8	23.2	20.4	8.25	Oxide
MSOX-3	0.05	NA	NA	1.6	84.5	82.9	54.08	Oxide
MCOX-3	0.04	NA	NA	1.3	75.7	74.5	60.56	Oxide
MSOX-2	0.02	NA	NA	0.6	4.2	3.6	6.72	Oxide
MSOX-1	0.01	NA	NA	0.3	59.0	58.7	188.80	Oxide

Note * (kg $CaCO_3$ equivalent/tonne)

TABLE 3
Barneys Canyon South, North Deposit
Static Testing Data

Sample ID	Sulphur (S)T	Sulphate (SO4)	Sulphide (S)	AP*	NP*	NNP*	NP/AP	Notes	
NP-2	0.11	<0.01	0.11	3.4	4.7	1.3	1.37	Quartzite	
NP-3	0.03	NA	NA	0.9	63.3	62.4	67.52	Quartzite	
NW-1	0.03	NA	NA	0.9	2.1	1.2	2.24	Sandstone	
NP-1	0.02	NA	NA	0.6	35.8	35.2	57.28	Quartzite	
NW-2	0.02	NA	NA	0.6	2.3	1.7	3.68	Quartzite	
NW-7	0.02	NA	NA	0.6	6.6	6.0	10.56	Quartzite	
NW-6	0.01	NA	NA	0.3	9.9	9.6	31.68	Quartzite	
NW-8	0.01	NA	NA	0.3	24.6	24.3	78.72	Quartzite	
NP-4	<0.01	NA	NA	<0.3	28.4	28.4	94.67	clay BXA	
NP-5	<0.01	NA	NA	<0.3	552.0	552.0	1840.00	Dolomite	
NP-6	<0.01	NA	NA	<0.3	981	981.0	3270.00	Dolomite	Road Cut
NP-7	<0.01	NA	NA	<0.3	<0.1	0.0	0.00	Quartzite	Road Cut
NP-8	<0.01	NA	NA	<0.3	14.5	14.5	48.33	Quartzite	Road Cut
NP-9	<0.01	NA	NA	<0.3	913.0	913.0	3043.33	Dolomite	Road Cut
NW-10	<0.01	NA	NA	<0.3	5.3	5.3	17.67	Sandstone	
NW-3	<0.01	NA	NA	<0.3	441.0	441.0	1470.00	Dolomite	
NW-4	<0.01	NA	NA	<0.3	78.5	78.5	261.67	Quartzite	
NW-5	<0.01	NA	NA	<0.3	8.1	8.1	27.00	Sandstone	
NW-9	<0.01	NA	NA	<0.3	8.0	8.0	26.67	Quartzite	

Note * (kg $CaCO_3$ equivalent/tonne)

TABLE 4
Barneys Canyon South, South Deposit
Static Testing Data

Sample ID	Sulphur (S)T	Sulphate (SO4)	Sulphide (S)	AP*	NP*	NNP*	NP/AP	Notes	
SS-1	8.75	NA	NA	273.4	<0.1	-273.4	0.00	Sulphide Waste Rock	
SP-5	1.01	0.17	0.84	26.3	36.0	9.8	1.37	Quartzite	
SW-2	0.79	0.4	0.39	12.2	3.9	-8.3	0.32	Clay BXA	
SW-21	0.45	<0.01	0.45	14.1	4.1	-10.0	0.29		
SW-13	0.41	<0.01	0.41	12.8	5.2	-7.6	0.41		
SW-14	0.38	<0.01	0.38	11.9	<0.1	-11.9	0.00		
SW-10	0.32	0.41	<0.01	<0.3	<0.1	0.0	0.00		
SW-8	0.28	<0.01	0.28	8.8	1.3	-7.5	0.15		
SW-16	0.23	<0.01	0.23	7.2	0.1	-7.1	0.01		
SW-4	0.13	0.07	0.06	1.9	0.8	-1.1	0.43	Clay BXA	Road Cut
SW-20	0.1	0.05	0.05	1.6	<0.1	-1.6	0.00		
SW-12	0.09	0.06	0.03	0.9	<0.1	-0.9	0.00		
SW-19	0.09	NA	NA	2.8	8.1	5.3	2.88		
SW-7	0.09	<0.01	0.09	2.8	3.0	0.2	1.07		
SW-3	0.08	NA	NA	2.5	18.8	16.3	7.52	Clay BXA	Road Cut
SW-6	0.08	<0.01	0.08	2.5	2.5	0.0	1.00		
SW-25	0.07	0.01	0.06	1.9	0.5	-1.4	0.27		
SW-23	0.06	<0.01	0.06	1.9	2.3	0.4	1.23		
SW-5	0.06	NA	NA	1.9	6.4	4.5	3.41	Clay BXA	Road Cut
SW-24	0.05	<0.01	0.05	1.6	<0.1	-1.6	0.00		
SP-6	0.04	NA	NA	1.3	38.9	37.7	31.12	Clay BXA	
SW-17	0.03	NA	NA	0.9	5.6	4.7	5.97		
SP-7	0.01	NA	NA	0.3	38.9	38.6	124.48	Quartzite	Road Cut
SP-1	<0.01	NA	NA	<0.3	<0.1	0.0	0.00	Quartzite	
SW-11	<0.01	NA	NA	<0.3	8.0	8.0	26.67		
SW-15	<0.01	NA	NA	<0.3	40.4	40.4	134.67		
SW-18	<0.01	NA	NA	<0.3	26.3	26.3	87.67		
SW-22	<0.01	<0.01	<0.01	0.0	<0.1	0.0	0.00		
SW-9	<0.01	NA	NA	<0.3	15.7	15.7	52.33		
Average				4.2	9.5	5.3	2.3	Average for waste samples only	

Note * (kg $CaCO_3$ equivalent/tonne)

CLIENT SAMPLE I.D.: SW-2
LAB SAMPLE I.D.: 921039-3

PARAMETER	UNITS	WEEK 1	WEEK 2	WEEK 3	WEEK 4	WEEK 5	WEEK 6	WEEK 7	WEEK 8	WEEK 9	WEEK 10	WEEK 11	WEEK 14	WEEK 17	WEEK 20
Leachate Quantity	mls	108	107	102	100	99	100	90	98	108	108				
pH	pH Units	6.26	5.90	6.83	7.23	6.79	6.26	6.31	6.95	6.94	6.96	7.00	7.06	6.74	7.04
Conductivity	umhos/cm	77	231	271	381	232	176	161	95	87	72	80	60	67	87
Sulfate	mg/L	<10	14	34	57	40	36	31	18	17	11	11	<10	10	<10
Cumulative Sulfate	Total mg	0	1	4	10	14	17	20	22	24	25				
Acidity	mg/L CaCO3	<10	17	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Cumulative Acidity	Tot. mg CaCO3	0	2	2	2	2	2	2	2	2	2				
Iron (Diss.)	mg/L	<0.03	<0.03	<0.03	<0.03	<0.03	0.05	0.04	<0.03	<0.03	0.04	<0.03	<0.03	<0.03	<0.08
Cumulative Iron	Total ug	0	0	0	0	0	5	9	9	9	13				
Alkalinity	mg/L CaCO3	6	6	10	16	6	13	16	16	13	13	713	18	8	18
pH of DI H2O	pH Units	6.80	6.60	5.51	5.56	5.48	6.11	5.60	6.54	5.55	6.03				

CLIENT SAMPLE I.D.: SW-4
LAB SAMPLE I.D.: 921039-4

PARAMETER	UNITS	WEEK 1	WEEK 2	WEEK 3	WEEK 4	WEEK 5	WEEK 6	WEEK 7	WEEK 8	WEEK 9	WEEK 10	WEEK 11	WEEK 14	WEEK 17	WEEK 20
Leachate Quantity	mls	104	106	105	95	107	101	93	99	109	109				
pH	pH Units	6.53	6.53	7.10	7.33	7.05	6.56	6.40	7.11	7.08	7.10	7.10	7.16	2.78	7.15
Conductivity	umohs/cm	674	871	973	1140	763	574	460	235	184	177	150	74	1000	48
Sulfate	mg/L	74	76	86	97	25	56	47	26	21	17	15	<10	10	<10
Cumulative Sulfate	Total mg	8	16	25	34	37	42	47	49	52	53				
Acidity	mg/L CaCO3	13	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	[illegible]	<10
Cumulative Acidity	Tot. mg CaCO3	1	1	1	1	1	1	1	1	1	1				
Iron (Diss.)	mg/L	0.18	<0.03	0.03	<0.03	<0.03	<0.03	0.10	<0.03	<0.03	0.05	<0.03	<0.03	1.47	<0.03
Cumulative Iron	Total ug	19	19	22	22	22	22	31	31	31	37				
Alkalinity	mg/L CaCO3	21	15	16	26	6	23	29	23	19	19	19	19	7	19
pH of DI H20	pH Units	6.80	6.60	5.51	5.56	5.48	6.11	5.60	6.54	5.55	6.03			*	

Note. * may represent an analytical error, (premature preservation with HNO_3 suspected)

CLIENT SAMPLE I.D.: SP-5
LAB SAMPLE I.D.: 921039-2

PARAMETER	UNITS	WEEK 1	WEEK 2	WEEK 3	WEEK 4	WEEK 5	WEEK 6	WEEK 7	WEEK 8	WEEK 9	WEEK 10	WEEK 11	WEEK 14	WEEK 17	WEEK 20
										*				*	
Leachate Quantity	mls	133	130	122	147	134	129	136	129	130	138				
pH	pH Units	6.79	6.26	7.04	7.46	6.93	6.22	6.29	6.82	6.73	6.86	7.04	6.84	3.27	7.16
Conductivity	umohs/cm	88	130	106	71	59	76	66	72	55	40	34	40	300	48
Sulfate	mg/L	14	14	15	10	11	15	13	13	10	<10	<10	<10	<10	<10
Cumulative Sulfate	Total mg	2	4	6	7	8	10	12	14	15	15				
Acidity	mg/L CaCO3	11	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	62	<10
Cumulative Acidity	Tot. mg CaCO3	1	1	1	1	1	1	1	1	1	1				
Iron (Diss.)	mg/L	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	1.29	<0.03
Cumulative Iron	Total ug	0	0	0	0	0	0	0	0	0	0				
Alkalinity	mg/L CaCO3	11	13	10	16	10	10	13	19	16	13	13	13	<5	10
pH of DI H20	pH Units	6.80	6.60	5.51	5.56	5.48	6.11	5.60	6.54	5.55	6.03				

Note * may represent an analytical error, (premature preservation with HNO_3 suspected)

CLIENT SAMPLE I.D.: HP-2
LAB SAMPLE I.D.: 921039-1

PARAMETER	UNITS	WEEK 1	WEEK 2	WEEK 3	WEEK 4	WEEK 5	WEEK 6	WEEK 7	WEEK 8	WEEK 9	WEEK 10	WEEK 11	WEEK 14	WEEK 17	WEEK 20
Leachate Quantity	mls	131	127	116	124	115	108	110	102	120	114				
pH	pH Units	6.19	5.86	6.51	7.04	6.53	6.06	5.88	6.48	6.46	6.48	6.33	6.60	6.64	6.61
Conductivity	umohs/cm	100	147	177	119	101	74	74	43	36	34	24	17	18	16
Sulfate	mg/L	14	12	16	19	17	15	16	<10	<10	<10	<10	<10	<10	<10
Cumulative Sulfate	Total mg	2	3	5	8	10	11	13	13	13	13				
Acidity	mg/L CaCO3	13	<10	<10	<10	<10	11	<10	15	<10	<10	<10	<10	<10	<10
Cumulative Acidity	Tot. mg CaCO3	2	2	2	2	2	3	3	4	4	4				
Iron (Diss.)	mg/L	0.06	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.04	<0.03	<0.03	<0.03
Cumulative Iron	Total ug	8	8	8	8	8	8	8	8	8	8				
Alkalinity	mg/L CaCO3	6	<5	13	13	<5	6	6	6	6	6	10	7	6	6
pH of DI H2O	pH Units	6.80	6.60	5.51	5.56	5.48	6.11	5.60	6.54	5.55	6.03				

file SRK

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RECEIVED
MAR 30 1993

March 18, 1993
Project Number S113107

Barneys Canyon Mine
P.O. Box 311
Bingham Canyon, Utah
84006-0311

Attention: Dave Hodson

Dear Mr. Hodson:

RE: ACID BASE ACCOUNTING AND SHAKE FLASK TESTING RESULTS

This memo presents our conclusions and recommendations from the recent testing of samples from the South Barneys Canyon - South Deposit.

A total of 40 samples were collected from blast hole cuttings at the site. These samples were distributed uniformly over 10 drill holes, and at depths of 10, 20, 30 and 40 feet. The uniform distribution of samples adequately represents the material excavated from this area. Eight samples were sent to Chemex Laboratories in North Vancouver, British Columbia and 32 samples were sent to Core Laboratories in Aurora, Colorado for acid base accounting tests. Two composite samples were prepared from the Chemex samples, and were submitted for short term leach extraction tests.

Acid Base Accounting Test Results

Table 1 presents the acid base accounting results, sorted by NNP. A discussion of the criteria for interpretation of the test was provided in our letter to Dave Hodson, dated January 15, 1993. The following has been extracted from that letter:

> Acid base account tests are used to define the balance between potentially acid generating minerals (sulfides) and potentially acid consuming minerals (typically carbonates) in a sample. Theoretically a sample will only generate acidic leachate if the potential for acid generation (AP) exceeds the neutralization potential, (NNP) or an NP/AP ratio of less than 1. However, in a rock pile, the physical distribution of the potentially acid generating and acid neutralizing minerals may be sufficiently variable that acidic seeps may develop for NP/AP ratios greater than 1. For mine rock piles, it is generally accepted that samples with an NP/AP of less than 3:1 (but greater

than 1) do not clearly indicate a potential for acid generation. It is our opinion that where the sulfide and base mineralization is disseminated fairly uniformly in the rock mass (as is the case at Barneys Canyon) and is not concentrated on joints, that this ratio can be reduced to 2:1. A similar index based on NNP is used, where samples in the range of +20 to -20 kg $CaCO_3$ equivalent/tonne are in this uncertain range. If a sample falls within this range, kinetic testing is generally required to determine the likelihood for contaminant release and acid generation. In addition where sulfide sulfur is low, generally less than 0.1%, it is considered that the potential for acid generation is insignificant, even if no NP is available. In this case, however, metal leaching may still pose a potential concern.

An additional consideration is the apparently low reactivity of the sulfides remaining in the rock. There are indications that the material to be mined from the South Barneys Canyon - South Deposit has already been exposed to a certain amount of chemical weathering. The majority of the material to be mined is above the natural groundwater table and the porous nature of the rocks has allowed air and water to reach sulfide particles within the rock mass. Any reactive sulfide particles would have likely already oxidized to sulfate. Therefore it is considered likely that any remaining sulfides have a relatively low reactivity.

Test results from the recent samples indicate the overall potential for acid generation is low. In a well blended rock pile, there would be a net positive NNP, and a net NP:AP ratio of 2.1. The distribution of potentially acid producing and acid consuming materials is however not uniformly distributed in the rock to be mined:

- 5/40 samples tested would be considered likely to produce acidity;
- 9/40 samples have a potential to generate acidity, but have sufficiently low sulfide contents that the net acidity produced would be very low;
- 5/40 samples are in the uncertain range for acid generation, where kinetic tests are required to determine the likelihood of acid generation. However, these samples have such a small proportion of sulfide and neutralizing minerals that they are considered "inert", or non-reactive;
- 10/40 samples are non acid producing, however the total NP of these samples is relatively low, therefore the samples are not considered acid consumers; and,
- 11/40 samples are acid consuming.

Because the potentially acid generating rock (HH10) is not located spatially near to the neutralizing materials (HH3, HH4 and HH8), there is some concern that a well blended pile would be difficult to produce. Selected removal of some of the potentially acid producing materials would provide some assurance that the blend of 2:1 can be maintained uniformly throughout the pile. For example, if the material in the vicinity of the HH10 drill hole were removed and hauled to the strongly acid consuming Barneys Canyon Mine piles, the overall NP:AP ratio remaining would be approximately 3:1.

Ms. Heppler indicated that the iron enriched areas within the pit are distributed in a random clustered pattern, possibly with a weak structural control, rather that an easily identified lithologic pattern. It would probably be very difficult to segregate materials based on their acid potential.

We feel that while there is the potential for localized zones of acid generating materials: the low reactivity of the sulfides and the overall composition of the pile will prevent the development of acidic drainage, even at a 2:1 ratio, provided an even blend can be maintained. If it is not possible to maintain the blend, the material which is likely to produce acidity could be selectively removed and hauled to an alternative disposal site.

Short Term Extraction Tests

Extraction tests, or "shake flask" tests are used to quantify the total contaminant load available for dissolution. The test does not quantify the rate of release over time.

Two composite samples were prepared from the samples sent to Chemex laboratories. These represent material with a "high" and moderate sulfate content. The samples were mixed with a weak acidic leachate (pH 4.2) at a solution to solids ratio of 2:1, agitated for 24 hours, filtered and analyzed for pH, conductivity, sulfate, alkalinity, and metals by ICP. The detailed procedure used by Chemex is attached. Test results are presented in Tables 2 and 3.

Test results indicate a very rapid response of neutralizing minerals to the weak acid leachate. The pH of the final solution for both samples was greater than 8.0. Alkalinity levels reached 43 and 30 mg/L $CaCO_3$ equivalent respectively for each of the samples. The rapid response of pH and alkalinity to the acidic leachate used for the test, indicates the samples would respond rapidly in the field to neutralize any acidic seepage developing within the rock pile. Conductivity levels were elevated to levels exceeding 170 umhos/cm, this high conductivity represents soluble salts, including the sulfate and other ionic species in solution.

Sulfate levels in the final leachate were 26 and 24 mg/L respectively. As there was a small amount of sulfate (from the sulfuric acid) in the original leachate, this represents a net sulfate release of 22 and 20 mg/L, or a maximum soluble load of about 40 mg/kg of rock, under the relatively aggressive testing conditions. It is our experience that only a small portion of the maximum soluble load is released under normal conditions in dry deposited rock piles. However, when this is magnified to the tonnages of waste rock in the piles, even a small percentage release of the sulfate could represent a significant concentration (on the order of 1000 mg/L) discharging from the pile. It is our opinion that any release of sulfates would be over the short term, and would be sufficiently diluted by the regional surface and groundwaters to mitigate any impact to the downstream system.

Metal concentrations in the final leachate were generally very low. An appreciable amount of calcium was released, probably due to dissolution of carbonate minerals. Trace levels of arsenic, nickel and molybdenum were detected in the HH1 composite. The solids analysis indicates there is a significant quantity of arsenic available for release, however the tests indicate only a small portion is readily soluble. It appears that there is very little concern with respect to metal leaching from material represented by these sample composites.

Summary and Recommendations

Based on the recent test results, the material represented by the test samples should present no significant concerns in terms of acid generation or water quality in a well blended pile. It is critical that this blend is maintained at an NP:AP ratio of greater than 2:1, therefore, if blending cannot be achieved on a small scale (<1 meter separation), selected removal of the sulfide enriched material is recommended.

In the absence of acid generation, there is a potential for a short term release of sulfate from rock dumps. To avoid flushing from the dump, we recommend that the dump be placed so as to fill the base of the valley allowing the stream flow to be directed, in a channel, over the dump. In this manner, impoundment behind the dump and the associated seepage and leaching is eliminated. SBCS

The 32 sample rejects, from the testing at Core Laboratories, have been sent to Cominco Engineering Services Laboratories in Vancouver (CESL). The samples should represent coarser grained material from the drill cuttings. We recommend the following 5 samples or sample composites be submitted for shake flask testing:

- HH10 (10, 20, 30)
- HH09 (20, 30, 40)
- HH04 (10, 20, 40)
- HH08 (20, 30, 40)
- HH07 (10, 20, 30)

The testing procedure used for the previous samples (at Chemex) is recommended. Additionally, paste pH tests should be done on all 32 original samples. CESL generally charges us for the labour only for these tests, @$29/hr. I think all of them could be done within 2 hours.

Please call if you have any questions or comments.

Yours truly

STEFFEN ROBERTSON AND KIRSTEN (CANADA) INC.

A. MacG. Robertson, P.Eng.
Principal

KSS/LMB/AMR
073/kss

TABLE 1
BARNEYS CANYON MINE, ACID BASE ACCOUNTING

SORTED BY NNP - ALL SAMPLES

Sample	Depth (ft)	S (tot) %	S (SO4) %	S (S 2-) %	AP	NP	NNP	NP/AP
HH10	10	0.9	0.33	0.57	17.8	2.7	-15.1	0.15
HH10	30	0.9	0.42	0.48	15.0	0.8	-14.2	0.05
HH10	20	0.79	0.29	0.50	15.6	1.8	-13.8	0.12
HH09	20	0.5	0.12	0.38	11.9	1.8	-10.1	0.15
HH07	10	1.89	1.54	0.35	10.9	1.8	-9.1	0.16
HH09	40	0.84	0.63	0.21	6.6	1.8	-4.8	0.27
HH07	40	0.4	0.2	0.20	6.3	1.8	-4.5	0.29
HH09	30	1.04	0.92	0.12	3.8	0.4	-3.4	0.11
HH05	20	0.24	0.06	0.18	5.6	2.5	-3.1	0.44
HH02	30	0.194	0.08	0.11	3.6	1	-2.56	0.28
HH02	40	0.266	0.17	0.10	3.0	1	-2.00	0.33
HH03	10	0.6	0.04	0.56	17.5	15.8	-1.7	0.90
HH02	20	0.23	0.13	0.10	3.1	2	-1.13	0.64
HH05	10	0.11	<.01	0.11	3.4	3.3	-0.1	0.96
HH06	40	0.13	0.06	0.07	2.2	2.3	0.1	1.05
HH06	10	0.08	0.02	0.06	1.9	2	0.1	1.07
HH01	40	0.418	0.30	0.12	3.7	4	0.31	1.08
HH05	30	0.12	0.02	0.10	3.1	3.5	0.4	1.12
HH05	40	0.06	0.02	0.04	1.3	1.8	0.6	1.44
HH07	20	1.47	1.46	0.01	0.3	1.8	1.5	5.76
HH06	30	0.03	0.02	0.01	0.3	1.8	1.5	5.76
HH10	40	0.28	0.31	0.00	0.0	1.8	1.8	>18
HH07	30	0.66	0.69	0.00	0.0	1.8	1.8	>18
HH09	10	0.4	0.33	0.07	2.2	4.3	2.1	1.97
HH01	10	0.558	0.47	0.09	2.8	5	2.25	1.82
HH01	30	0.626	0.57	0.06	1.8	6	4.25	3.43
HH06	20	0.01	<.01	0.01	0.3	4.8	4.5	15.36
HH08	10	0.04	0.04	0.00	0.0	4.8	4.8	>48
HH02	10	0.035	0.03	0.01	0.2	6	5.84	38.40
HH03	20	0.13	0.04	0.09	2.8	10.4	7.6	3.70
HH04	30	0.1	<.01	0.10	3.1	10.9	7.8	3.49
HH01	20	0.519	0.47	0.05	1.5	13	11.47	8.49
HH04	20	0.05	<.01	0.05	1.6	16.7	15.1	10.69
HH04	40	0.08	0.02	0.06	1.9	20.5	18.6	10.93
HH04	10	0.05	0.05	0.00	0.0	23.6	23.6	>236
HH08	20	0.09	<.01	0.09	2.8	28.6	25.8	10.17
HH03	30	0.13	0.02	0.11	3.4	29.9	26.5	8.70
HH08	30	0.07	0.05	0.02	0.6	27.1	26.5	43.36
HH03	40	0.14	0.02	0.12	3.8	38.5	34.8	10.27
HH08	40	0.02	0.01	0.01	0.3	37.7	37.4	120.64
AVERAGE (NET ROCK PILE COMPOSITION)					4.1	8.7	4.5	2.1

TABLE 2

BARNEYS CANYON MINE, SHAKE FLASK TEST RESULTS

Leaching Solution:

pH	4.2
Conductivity (umhos/cm)	21.7
Sulphate (SO4) (mg/L)	4.2

Test Results:

Parameter	HH1 Comp	HH2 Comp
pH (after 1 hour of contact)	8.6	8.2
pH (after 2 hours of contact)	8.6	8.2
pH (Final)	8.4	8.2
Conductivity (umhos/cm)	192	177
Alkalinity (mg/L CaCO3 eq.)	43	30
Net Sulphate (SO4) (mg/L)	22	20

METALS (mg/L)

	HH1 Comp	HH2 Comp
As	0.05	< 0.05
Ba	0.3	0.1
Ca	21	10
Cu	< 0.01	< 0.01
Fe	< 1	< 1
K	5	5
Mg	4	2.8
Mn	< 0.01	< 0.01
Mo	0.34	0.02
Ni	0.05	0.04
P	< 1	< 1
Pb	< 0.05	0.05
Sr	0.11	0.07
Zn	< 0.01	< 0.01

* Selected metals not included (metals where the solids content was below detection limit)

TABLE 3

BARNEYS CANYON MINE, SHAKE FLASK TEST RESULTS: CALCULATIONS

Parameter	Solids (mg/kg)		Leachate (mg/L)		Load (mg/kg)		% Extraction	
	HH1 Comp	HH2 Comp	HH1 Comp	HH2 Comp	HH1 Comp	HH2 Comp	HH1 Comp	HH2 Comp
SO4	4500	1000	22	20	44	40	0.98	4.00
As	178	160	0.05	< 0.05	0.1	< 0.1	0.06	< 0.06
Ba	520	1520	0.3	0.1	0.6	0.2	0.12	0.01
Ca	1500	800	21	10	42	20	2.80	2.50
Cu	6	6	< 0.01	< 0.01	< 0.02	< 0.02	< 0.33	< 0.33
Fe	13100	21700	< 1	< 1	< 2	< 2	< 0.02	< 0.01
K	1600	1200	5	5	10	10	0.63	0.83
Mg	700	500	4	2.8	8	5.6	1.14	1.12
Mn	15	115	< 0.01	< 0.01	< 0.02	< 0.02	< 0.13	< 0.02
Mo	2	2	0.34	0.02	0.68	0.04	34.00	2.00
Ni	4	24	0.05	0.04	0.1	0.08	2.50	0.33
P	80	70	< 1	< 1	< 2	< 2	< 2.50	< 2.86
Pb	20	12	< 0.05	0.05	< 0.1	0.1	< 0.50	0.83
Sr	56	45	0.11	0.07	0.22	0.14	0.39	0.31
Zn	14	170	< 0.01	< 0.01	< 0.02	< 0.02	< 0.14	< 0.01

TABLE 4
BARNEYS CANYON MINE, ACID BASE ACCOUNTING

SORTED BY NNP - HH10 REMOVED

Sample	Depth (ft)	S (tot) %	S (SO4) %	S (S 2-) %	AP	NP	NNP	NP/AP
HH09	20	0.5	0.12	0.38	11.9	1.8	-10.1	0.15
HH07	10	1.89	1.54	0.35	10.9	1.8	-9.1	0.16
HH09	40	0.84	0.63	0.21	6.6	1.8	-4.8	0.27
HH07	40	0.4	0.2	0.20	6.3	1.8	-4.5	0.29
HH09	30	1.04	0.92	0.12	3.8	0.4	-3.4	0.11
HH05	20	0.24	0.06	0.18	5.6	2.5	-3.1	0.44
HH02	30	0.194	0.08	0.11	3.6	1	-2.56	0.28
HH02	40	0.266	0.17	0.10	3.0	1	-2.00	0.33
HH03	10	0.6	0.04	0.56	17.5	15.8	-1.7	0.90
HH02	20	0.23	0.13	0.10	3.1	2	-1.13	0.64
HH05	10	0.11	<.01	0.11	3.4	3.3	-0.1	0.96
HH06	40	0.13	0.06	0.07	2.2	2.3	0.1	1.05
HH06	10	0.08	0.02	0.06	1.9	2	0.1	1.07
HH01	40	0.418	0.30	0.12	3.7	4	0.31	1.08
HH05	30	0.12	0.02	0.10	3.1	3.5	0.4	1.12
HH05	40	0.06	0.02	0.04	1.3	1.8	0.6	1.44
HH07	20	1.47	1.46	0.01	0.3	1.8	1.5	5.76
HH06	30	0.03	0.02	0.01	0.3	1.8	1.5	5.76
HH07	30	0.66	0.69	0.00	0.0	1.8	1.8	>18
HH09	10	0.4	0.33	0.07	2.2	4.3	2.1	1.97
HH01	10	0.558	0.47	0.09	2.8	5	2.25	1.82
HH01	30	0.626	0.57	0.06	1.8	6	4.25	3.43
HH06	20	0.01	<.01	0.01	0.3	4.8	4.5	15.36
HH08	10	0.04	0.04	0.00	0.0	4.8	4.8	>48
HH02	10	0.035	0.03	0.01	0.2	6	5.84	38.40
HH03	20	0.13	0.04	0.09	2.8	10.4	7.6	3.70
HH04	30	0.1	<.01	0.10	3.1	10.9	7.8	3.49
HH01	20	0.519	0.47	0.05	1.5	13	11.47	8.49
HH04	20	0.05	<.01	0.05	1.6	16.7	15.1	10.69
HH04	40	0.08	0.02	0.06	1.9	20.5	18.6	10.93
HH04	10	0.05	0.05	0.00	0.0	23.6	23.6	>236
HH08	20	0.09	<.01	0.09	2.8	28.6	25.8	10.17
HH03	30	0.13	0.02	0.11	3.4	29.9	26.5	8.70
HH08	30	0.07	0.05	0.02	0.6	27.1	26.5	43.36
HH03	40	0.14	0.02	0.12	3.8	38.5	34.8	10.27
HH08	40	0.02	0.01	0.01	0.3	37.7	37.4	120.64
AVERAGE (NET ROCK PILE COMPOSITION)					3.3	9.4	6.2	2.9

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April 15, 1993
Project Number K103101

Barneys Canyon Mine
P.O. Box 311
Bingham Canyon, Utah
84006-0311

By FAX

Attention: Mr. Dave Hodson

Dear Mr. Hodson:

RE: SUMMARY OF ABA ACCOUNTING RESULTS FROM THE MELCO DEPOSIT

This letter summarizes the testing results from 55 samples collected from the Melco deposit.

A total of 10 drill core samples from each of the major rock units were collected and submitted for testing. The rock units comprise:

- non-calcareous sandstone;
- calcareous sandstone;
- quartzite;
- carbonaceous dikes; and,
- sulfide rock;

Five samples were also collected from a breccia zone in the waste rock.

The proportion of each of these materials is currently under assessment by Barneys Canyon Mine personnel. It is estimated that the carbonaceous and sulphitic rock will comprise less than 5 percent of the total waste dump composition. Table 1 lists the drill holes and depths at which each of the samples was collected.

The samples were submitted to Core Laboratories in Aurora, Colorado for acid base accounting tests.

Acid Base Accounting Results

Acid base accounting tests are used to define the balance between potentially acid generating minerals (sulphides) and acid consuming minerals (typically carbonates). Table 1 presents the acid base accounting test results for each of the 55 samples. These are discussed by rock type below.

Non-Calcareous Sandstone

The non-calcareous sandstone is relatively "barren" with respect to sulphide and carbonate mineralization. Sulphur levels do not exceed 0.01 percent (the detection limit), and therefore do not have any significant potential to oxidize and produce acidity. The neutralization potential (NP) of the samples is typically very low, ranging from 0.9 to 4.1 kg $CaCO_3$ equivalent/tonne, and a single sample with an NP of 22.5. The average NNP from the 10 samples tested was 3.9. These samples are essentially inert and would not contribute acidity to the rock pile, nor do they contain sufficient NP to neutralize acidity generated from other rock types within the pile.

Barneys Canyon Mine have reported that a significant portion of the dumps will be comprised of the non-calcareous sandstone.

Calcareous Sandstone

Sulphur levels in the calcareous sandstone samples are very low, less than 0.01 percent. This material is therefore unlikely to oxidize or produce acidity. The neutralization potential ranges from <0.1 to 98.4 kg $CaCO_3$ equivalent/tonne, with an average value of 41.8. Rock from this unit can be classified as acid consuming.

No estimate of the proportion of calcareous sandstone has been made.

Quartzite

The sulphur content of the 10 quartzite samples is very low, ranging from <0.01 to 0.02 percent. The neutralization potential is also relatively low, ranging from 0.9 to 36.4 kg $CaCO_3$ equivalent/tonne. Six of the samples are in the range of 0.9 to 3.4 kg $CaCO_3$ equivalent/tonne, and are considered non-reactive. The remaining 4 samples contain 21.7 to 36.4 kg $CaCO_3$ equivalent/tonne NP, and are considered acid consuming.

A significant portion of the dumps will be comprised of the quartzite.

Carbonaceous Dikes

The carbonaceous material contains a significant proportion of sulphide mineralization. Total sulphur levels range from 0.05 to 4.05 percent. Sulphate levels are low, ranging from <0.01 to 0.18 percent. Assuming the total sulphur less the sulphate sulphur is equivalent to the sulphide sulphur content, the sulphide content ranges from 0.03 to 3.9 percent, and has an average value of 1.25.

The NP measured in this material ranges from <0.1 to 4.6, indicating a low acid neutralization potential. The majority of samples are considered likely to generating acid. Two of the sample are in the uncertain range, where kinetic tests are required to determine the likelihood for acid generation.

It is possible that the sulphide sulphur, or AP, content is actually somewhat less than reported. If some of the sulphur is present as barite, it will report to the sulphide sulphur, thus overestimating the potential for acid production. As discussed, we have initiated work to quantify the amount of barite, and recalculate the AP.

Barneys Canyon Mine have indicated that less than 1 percent of this material will report to the waste dumps.

Sulphide rock

The sulphur content of this material ranges from 0.04 to 2.6 percent. Sulphates range from <0.01 to 0.14. Assuming sulphide content is equivalent to the total sulphur less the sulphate sulphur (see the previous comment on barite), the sulphide content is in the range of <0.01 to 2.46, with an average of 0.93 percent. Five of the samples contain less than 2 kg $CaCO_3$ equivalent/tonne NP, while 5 are in the range of 9.1 to 38.5 kg $CaCO_3$ equivalent/tonne NP. Six of the samples are considered likely to produce acidity. Three are in the range of uncertainty for acid generation, and one sample is considered acid consuming.

Barneys Canyon Mine have indicated that less than 4 percent of the sulphide rock will report to the waste dumps.

Note. This should read less than 4 percent of the dump material will contain sulfide.

Breccia

Five samples from the breccia rock were tested. Sulphide contents range from <0.01 to 0.09 percent, indicating a relatively low potential to generate acidity. The NP of these samples range from 2.3 to 9.7 kg $CaCO_3$ equivalent/tonne NP. The samples do not have a clear potential to either generate or consume acidity.

No estimate of the proportion of breccia has been made.

Overall Acid Potential

Table 2 provides an estimate of the acid generation potential for the dumps, assuming the majority of the material is comprised of non-calcareous sandstone and quartzite. This will be refined once the results of the block model are available to us. The percentages assume a worse case, in that the calcareous sandstone is probably under-represented in the composition. Assuming these samples adequately represent each of the rock units, it is considered unlikely that the pile could generate acid. There is however a potential for the release of sulphate if the carbonaceous and sulphitic rocks oxidize. Strategies for placement of these materials, and a risk analysis comparing the alternatives will be sent to you within the next week.

Yours truly,

STEFFEN ROBERTSON AND KIRSTEN (CANADA) INC.

for A. MacG. Robertson, P.Eng.
Principal

KSS/LMB/AMR
073/AMR

attach.

TABLE 1
Melco Deposit - Acid Base Accounting Test Results

Sample	Depth From	To	S (tot)	S (SO4)	S (S2-)	AP	NP	NNP	NP/AP	Notes
MC-280D	504	514	<0.01	0.02	<0.01	<0.3	4.4 >	4.1 >	14.5	Non-calcareous Sandstone
MC-281D	115	125	<0.01	0.02	<0.01	<0.3	1.1 >	0.8 >	3.6	Non-calcareous Sandstone
MC-319D	10	20	<0.01	<0.01	<0.01	<0.3	0.2 >	-0.1 >	0.7	Non-calcareous Sandstone
MC-352P	775	780	0.01	<0.01	0.01	0.3	1.4	1.1	4.5	Non-calcareous Sandstone
MC-353D	20	30	<0.01	0.02	<0.01	<0.3	0.9 >	0.6 >	3.0	Non-calcareous Sandstone
MC-361D	260	265	<0.01	<0.01	<0.01	<0.3	2.2 >	1.9 >	7.3	Non-calcareous Sandstone
MC-361D	390	395	0.01	0.04	<0.01	<0.3	2.8 >	2.5 >	9.2	Non-calcareous Sandstone
MC-363P	690	700	<0.01	<0.01	<0.01	<0.3	22.8 >	22.5 >	75.2	Non-calcareous Sandstone
MC-374D	383	393	<0.01	<0.01	<0.01	<0.3	1.6 >	1.3 >	5.3	Non-calcareous Sandstone
MC-377D	10	30	<0.01	0.02	<0.01	<0.3	1.6 >	1.3 >	5.3	Non-calcareous Sandstone
MC-280D	49	54	<0.01	0.03	<0.01	<0.3	82 >	81.7 >	270.6	Calcareous Sandstone
MC-280D	164	174	<0.01	0.02	<0.01	<0.3	<0.1 >	-0.3	0.0	Calcareous Sandstone
MC-280D	334	341	<0.01	0.03	<0.01	<0.3	68.3 >	68.0 >	225.4	Calcareous Sandstone
MC-281D	715	720	<0.01	<0.01	<0.01	<0.3	98.4 >	98.1 >	324.7	Calcareous Sandstone
MC-319D	80	90	<0.01	<0.01	<0.01	<0.3	0.6 >	0.3 >	2.0	Calcareous Sandstone
MC-319D	90	100	<0.01	<0.01	<0.01	<0.3	<0.1 >	-0.3 >	0.0	Calcareous Sandstone
MC-361D	130	135	<0.01	<0.01	<0.01	<0.3	3.4 >	3.1 >	11.2	Calcareous Sandstone
MC-361D	225	230	<0.01	0.02	<0.01	<0.3	23.2 >	22.9 >	76.6	Calcareous Sandstone
MC-361D	215	220	<0.01	<0.01	<0.01	<0.3	1 >	0.7 >	3.3	Calcareous Sandstone
MC-363P	615	625	<0.01	<0.01	<0.01	<0.3	140 >	139.7 >	462.0	Calcareous Sandstone
MC-280D	820	830	<0.01	<0.01	<0.01	<0.3	21.7 >	21.4 >	71.6	Quartzite
MC-281D	295	300	0.01	<0.01	0.01	0.3	26.4	26.1	84.5	Quartzite
MC-281D	400	410	<0.01	<0.01	<0.01	<0.3	1.2 >	0.9 >	4.0	Quartzite
MC-319D	485	490	0.01	<0.01	0.01	0.3	3.4	3.1	10.9	Quartzite
MC-252P	705	710	<0.01	0.04	<0.01	<0.3	2.4 >	2.1 >	7.9	Quartzite
MC-353D	305	310	<0.01	<0.01	<0.01	<0.3	2.6 >	2.3 >	8.6	Quartzite
MC-361D	735	740	<0.01	0.02	<0.01	<0.3	2.6 >	2.3 >	8.6	Quartzite
MC-363P	578	580	<0.01	<0.01	<0.01	<0.3	24.2 >	23.9 >	79.9	Quartzite
MC-374D	173	183	0.02	0.04	<0.01	<0.3	36.4 >	36.1 >	120.1	Quartzite
MC-377D	101	110	<0.01	<0.01	<0.01	<0.3	0.9 >	0.6 >	3.0	Quartzite
MC-280D	798	801	0.53	0.09	0.44	13.8	0.9	-12.9	0.1	Carboneceous Dikes
MC-319D	385	390	1.21	0.18	1.03	32.2	<0.1	-32.2	0.0	Carboneceous Dikes
MC-319D	390	395	0.85	0.16	0.69	21.6	<0.1	-21.6	0.0	Carboneceous Dikes
MC-319D	400	405	0.07	0.04	0.03	0.9	1.2	0.3	1.3	Carboneceous Dikes
MC-319D	695	700	0.05	<0.01	0.05	1.6	2	0.4	1.3	Carboneceous Dikes
MC-319D	820	825	1.82	0.17	1.65	51.6	<0.1	-51.6	0.0	Carboneceous Dikes
MC-353D	784	790	0.51	0.03	0.48	15.0	3	-12.0	0.2	Carboneceous Dikes
MC-377D	483	491	3.17	0.18	2.99	93.4	<0.1	-93.4	0.0	Carboneceous Dikes
MC-377D	906	911	1.27	<0.01	1.27	39.7	<0.1	-39.7	0.0	Carboneceous Dikes
MC-377D	911	917	4.05	0.15	3.9	121.9	4.6	-117.3	0.0	Carboneceous Dikes
MC-319D	995	1000	1.78	<0.01	1.78	55.6	1.6	-54.0	0.0	Sulphide Rock
MC-319D	1000	1005	0.98	0.14	0.84	26.3	<0.1	-26.3	0.0	Sulphide Rock
MC-352P	1005	1010	2.6	0.14	2.46	76.9	<0.1	-76.9	0.0	Sulphide Rock
MC-352P	1060	1065	1.09	0.05	1.04	32.5	38.5	6.0	1.2	Sulphide Rock
MC-353D	970	975	0.45	0.2	0.25	7.8	9.3	1.5	1.2	Sulphide Rock
MC-353D	990	995	0.07	0.02	0.05	1.6	<0.1	-1.6	0.0	Sulphide Rock
MC-353D	1025	1030	0.04	0.04	<0.01	<0.3	29.7 >	29.4 >	98.0	Sulphide Rock
MC-361D	792	797	1.23	0.03	1.2	37.5	9.1	-28.4	0.2	Sulphide Rock
MC-361D	820	825	0.41	0.03	0.38	11.9	16	4.1	1.3	Sulphide Rock
MC-377D	980	990	1.3	0.02	1.28	40.0	0.5	-39.5	0.0	Sulphide Rock
MC-319D	750	755	0.09	<0.01	0.09	2.8	9.7	6.9	3.4	Breccia
MC-352P	830	835	<0.01	0.02	<0.01	<0.3	3 >	2.7 >	9.9	Breccia
MC-361D	680	684	0.13	<0.01	0.13	4.1	3.5	-0.6	0.9	Breccia
MC-374D	272	282	0.1	<0.01	0.1	3.1	5.3	2.2	1.7	Breccia
MC-377D	815	825	<0.01	<0.01	<0.01	<0.3	2.3 >	2.0 >	7.6	Breccia

TABLE 2
Summary Results

Rock Unit	avg AP	avg NP	avg NNP	avg NP/AP	% in rock piles
Breccia	2.0	4.8	2.8	2.4	1
Calcareous Sandstone	<0.3	41.7	41.7	> 139.0	1
Carboneous Dikes	39.2	1.2	-38.0	0.0	1
Non-calcareous Sandstone	<0.3	3.9	3.9	> 13.0	44
Quartzite	0.1	12.2	12.1	194.9	45
Sulphide Rock	29.0	10.5	-18.5	0.4	4
Overall Weighted Average	1.6	8.1	6.5	5.1	

WASTE DUMP COVER DESIGN
A Modeling Study

Prepared for:

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WASTE DUMP COVER DESIGN
A Modeling Study

1.0 INTRODUCTION

An important goal of the reclamation of waste rock piles generated by mining operations is to minimize infiltration into the waste rock since such infiltration may adversely affect the quality of underlying ground water. In this context, infiltration is defined as water which migrates through a soil cover and passes into the waste rock beneath the cover. As part of the design of reclamation plans for waste rock dumps at the Kennecott Barneys Canyon Mine located near Salt Lake City, Utah, Water, Waste & Land, Inc., (WWL) evaluated the hydrologic aspects of potential cover designs. This report summarizes the methods utilized, describes the data utilized, and presents the results of the study.

1.1 Study Description

Waste rock generated at the Barneys Canyon Mine can be readily categorized into two distinct types—oxide and sulfide. The primary distinction between the two categories is the amount of sulfide mineral present in the rock. Sulfide bearing rock has the potential to generate acid as it weathers in the presence of oxygen and water so that infiltration into the waste may mobilize metals contained in the rock. To minimize potential environmental impact, it is desirable to minimize the infiltration into the waste dumps.

The oxide type waste rock, on the other hand, has acid neutralizing potential so that mobilization of metals is of little concern. While infiltration migrating through the oxide waste rock dumps is not expected to mobilize metals, it may contain elevated concentrations of soluble salts which are in the waste rock. Again, it is desirable to minimize the amount of leachate generated so as to minimize potential impacts to ground water.

Various cover designs can be implemented to minimize infiltration into waste materials. The most obvious solution is to include a layer of material, either natural or synthetic, which has a low permeability to restrict infiltration into the waste. However, this obvious solution may not be appropriate in all circumstances, especially in arid and semi-arid climates where establishment of vegetation on the surface of the waste dump may be sufficient to eliminate percolation beyond the root zone (recharge) so that the low permeability layer is unnecessary. A landfill study performed by Stephens and Coons (1994) suggests that low permeability caps provide little, if any, reduction in infiltration below that naturally achieved in an arid environment.

To minimize the potential for infiltration and subsequent seepage from the sulfide waste rock, Kennecott has developed a waste management plan in which separate waste dumps will be constructed for the two types of waste rock. Because of the difference between the two material types, it was recognized that different cover designs may be necessary. In semi-arid climates similar to that of the mine area, previous studies have shown that a natural cover consisting of vegetation is usually appropriate for the oxide waste piles. Depending on the efficiency of vegetation in removing infiltrated precipitation, additional components (barrier layer, drainage layer, etc.) could be incorporated into the cover for the sulfide waste dumps.

1.2 Objectives

The primary objectives of this study were to:

1. Develop a cover design which is optimized to minimize infiltration into the oxide waste dumps through the use of available materials, and

2. Evaluate the potential to further reduce the infiltration into the sulfide waste dumps.

Secondary objectives of the study were to 1) evaluate the potential for failure of the cover and provide recommendations to minimize the risk of such failures and 2) recommend data collection methods which can be used to assess the performance of covers after implementation.

1.3 Approach

Although revegetation studies have been performed at the Barneys Canyon Mine, final cover has not been placed on existing waste dumps. Therefore, the performance of potential waste rock cover designs was evaluated using predictive models. In general, these models rely on given climatic data (either historical or synthesized) from which the various hydrologic components (infiltration, runoff, evapotranspiration, etc.) are computed.

Two mathematical models were utilized to estimate the amount of water which may percolate from the base of the waste rock piles after reclamation is complete. The HELP (Hydrologic Evaluation of Landfill Performance) model developed on behalf of the U.S. Environmental Protection Agency (EPA) was the primary tool utilized in this study. An overview of the HELP model is provided in the Appendix. A more physically based model, UNSAT2, was applied to the problem in an effort to evaluate potential limitations of the HELP model. A general description of the UNSAT2 program is also provided in the Appendix.

In Section 2, data utilized in the analyses are presented and compared with available site data. Results of the analyses are provided in Section 3 and recommendations regarding the cover designs are presented in Section 4.

2.0 DATA UTILIZED

The data utilized in the modeling study are described in this section. Climate data are discussed in the first subsection. Rationale for selection of the default HELP soils is presented in the second subsection.

2.1 Climate

As discussed previously, the HELP model requires various climatological data as input to perform the water balance on the soil cover. The precipitation data used in the modeling effort are described and compared to data collected in the vicinity of the mine in the first subsection. Temperature data are discussed in the second subsection while evaporation related data are presented in the final subsection.

2.1.1 Precipitation

The HELP model provides the user with three options regarding precipitation—a default 5 year data set, synthetic precipitation data for 1 to 20 years generated by the model, or user supplied daily precipitation depths. Because site specific daily data are not available, the synthetic precipitation generation option was selected. The precipitation data were computed based on the coefficients for Salt Lake City. To evaluate its adequacy, the generated precipitation data set was compared to historical data collected at six weather stations operated by the National Oceanic and Atmospheric Administration (NOAA) in the vicinity of the Barneys Canyon Mine and three relatively short-term data sets collected by Kennecott personnel. The weather data for the NOAA stations are available (in daily or summary format) from the National Climatic Data Center (1993). The precipitation data are summarized by location and month in Table 1.

As shown in Table 1, precipitation varies considerably with location with a minimum annual average of 11.8 inches at Grantsville to a maximum annual average of 24.8 inches at Kennecott's Bingham 6190 Yard station. The data collected at the Barneys Canyon Mine (BCM) gate covers only the period from June, 1990, to the present time. Because of the short duration of the weather record and the fact that the data includes precipitation received in 1993 (one of the wettest years on record in Salt Lake City), the means reported for the BCM gate are not considered representative. In addition, the winter data are somewhat suspect since the station is not fitted with the proper equipment to measure snowfall as an equivalent rainfall depth. A longer period of record is available at Kennecott's Bingham 6190 Yard station but it is believed that this station receives more precipitation than Barneys Canyon Mine because of its location and elevation. Of the three Kennecott stations, the Bingham Geology station is probably the most representative of precipitation received in the vicinity of Barneys Canyon.

TABLE 1
SUMMARY OF CLIMATIC STATIONS AND AVERAGE MONTHLY PRECIPITATION

Station Parameter	Salt Lake City	Salt Lake City NWSFO	Bingham Canyon	Bingham Canyon 2NE	Tooele	Grantsville	Bingham 6190 Yard	BCM Gate	Bingham Geology	HELP 20 Year Synthetic
Elevation (ft)	4300	4220	6110	5620	5070	4290	6190	5640	5580	N/A
Begin Date	01/02/28	07/01/48	07/01/48	11/01/74	01/29/19	05/22/56	1965	6/1990	1974	N/A
End Date	07/31/54	12/31/92	10/31/74	08/31/85	12/31/92	12/31/92	1988	Present	1988	N/A
Years	27	45	27	12	46	37	24	3	15	20
Coverage (%)	100	100	94	100	60	100	N/A	N/A	N/A	N/A
Miles from BCM	≈20	≈20	≈7	≈5	≈8	≈14	≈2	≈1	≈2	≈20
Direction	NE	NE	SW	SW	SW	W	S	SE	S	NE
January	1.46	1.26	2.06	1.33	1.20	0.60	1.9	0.7	1.0	1.42
February	1.32	1.20	1.85	1.34	1.31	0.80	1.8	1.0	1.1	1.09
March	1.74	1.79	2.15	2.50	2.07	1.27	2.8	1.2	1.9	1.46
April	1.92	2.05	2.66	1.81	2.30	1.50	2.7	4.2	1.5	1.88
May	1.46	1.76	1.91	2.73	1.89	1.34	2.7	3.0	1.8	1.14
June	1.01	0.86	1.80	1.10	1.02	0.92	1.7	1.3	0.7	1.04
July	0.60	0.74	1.06	1.73	0.81	0.73	1.3	1.0	1.3	0.99
August	0.91	0.85	1.17	1.51	0.87	0.76	1.4	1.0	1.3	0.93
September	0.63	1.09	1.17	1.94	1.16	0.92	1.8	2.0	1.2	1.14
October	1.53	1.30	1.52	1.61	1.54	1.04	2.0	1.9	1.4	0.95
November	1.44	1.33	1.73	1.84	1.71	0.99	2.4	1.3	1.8	1.21
December	1.27	1.33	2.34	1.57	1.47	0.87	2.3	2.6	1.3	1.43
Annual[1]	15.38	15.56	21.47	21.37	17.39	11.81	24.8	21.2	16.3	14.68

NOAA climate stations - Salt Lake City, Salt Lake City NWSFO, Bingham Canyon, Bingham Canyon 2NE, Tooele, and Grantsville.
Kennecott climate stations - Bingham 6190 Yard, BCM Gate, and Bingham Geology. Kennecott stations do not meet approved weather station standards. Data from these stations should be considered indicative only.
[1] - NOAA station annuals are average annual precipitation and Kennecott station annuals are the totals of average monthly precipitation.

Precipitation data for the six NOAA weather stations suggest that the precipitation record generated by the HELP model compares favorably with the Salt Lake City stations but is somewhat lower than stations in the vicinity of Bingham Canyon. While it is not believed that the mine receives as much precipitation as the Bingham Canyon stations, it is possible that it receives somewhat more than the HELP generated average of 14.7 inches. As part of the sensitivity analyses, HELP modeling was performed with higher precipitation amounts.

2.1.2 Temperature

Regardless of the precipitation data utilized, the HELP model generates temperature data for use in the computations. Again the Salt Lake City coefficients were selected for generation of the temperature data since it is closer to the mine than the other two Utah cities, Cedar City and Milford, contained in the data base. Temperature data for five NOAA weather stations located in the vicinity of the mine are presented in Table 2 along with the temperature data collected by Kennecott at the Bingham 6190 weather station. Comparison of the data presented in Table 2 indicates that HELP generated temperatures compare favorably with the Salt Lake City average temperatures and are similar to averages at other stations.

2.1.3 Evapotranspiration

Few weather stations in the vicinity of the Barneys Canyon Mine collect pan evaporation data. Pan evaporation data for the five stations for which data are available are presented in Table 3 along with the potential evapotranspiration values estimated by multiplying the pan values by 0.7. As shown, pan evaporation ranges from a low of about 43 inches (potential evapotranspiration of 30.1 inches) in Provo to a high of 73.4 inches (potential evapotranspiration of 51.4 inches) at the Saltair Salt Plant. This latter location is on the edge of the Great Salt Lake along the margins of the Great Salt Flat. It is unlikely that evaporation potential at the mine is as high as observed at this location. Based on values observed at the other stations, it is likely that the pan evaporation in the vicinity of Barneys Canyon is on the order of 50 inches per year which translates to a potential evapotranspiration of about 35 inches per year. It should be noted that the reported values do not include the winter months so that the actual evaporation potential is probably somewhat higher.

The HELP program does not report average values of potential evapotranspiration which are computed based on weather data. Evapotranspiration is limited in arid environments where potential evapotranspiration greatly exceeds precipitation as at the Barneys Canyon site. The annual total evapotranspiration computed by the HELP model is considerably less than the potential evapotranspiration observed at regional weather stations (14 inches versus about 35 inches).

TABLE 2
SUMMARY OF AVERAGE MONTHLY TEMPERATURES

Month	Bingham Canyon	Bingham Canyon 2NE	Salt Lake City	Salt Lake City NWSFO	Tooele	Bingham 6190 Yard	HELP 20 Year Synthetic
Jan	28	27	29	28	29	27	28.6
Feb	31	32	35	34	33	31	34.1
Mar	36	38	42	42	40	35	40.7
Apr	44	46	52	50	49	44	49.2
May	54	55	60	59	58	51	58.8
Jun	63	66	68	69	67	62	68.3
Jul	72	75	79	77	76	69	77.5
Aug	70	73	76	75	74	71	74.9
Sep	62	64	66	65	64	60	65.0
Oct	50	51	55	53	52	48	53.0
Nov	38	38	41	40	39	34	39.7
Dec	29	31	33	30	30	29	30.3
Ann	48	50	53	52	51	47	51.7

Temperatures are in degrees Fahrenheit
NOAA climate stations - Bingham Canyon, Bingham Canyon 2NE, Salt Lake City, Salt Lake City NWSFO, Tooele
Kennecott climate stations - Bingham 6190 Yard. Kennecott station does not meet approved weather station standards. Data from this station should be considered indicative only.

Therefore, the potential evapotranspiration computed by the HELP model is well within the measured potential evapotranspiration for the vicinity of the Barneys Canyon site.

An important parameter in the HELP model is the depth of the evaporative zone. According to the default information in the climatic data base, typical evaporative zone depths for Salt Lake City are 16 inches for non-vegetated surfaces, 32 inches for fair grass and 48 inches for excellent grass. Based on test plot studies at the Barneys Canyon Mine, the effective rooting depth on the reclaimed waste rock piles is expected to be about 24 inches (Golder Associates, 1994) so the evaporative zone depth was set to 24 inches for all HELP modeling.

The HELP model provides five vegetation choices for soil covers—bare ground, poor grass, fair grass, good grass and excellent grass—which determine the maximum leaf-area index for the crop.

TABLE 3
SUMMARY OF CLIMATIC STATIONS AND AVERAGE MONTHLY EVAPORATION

Station Parameter	Provo Airport		Provo Radio KYAK		Provo BYU		Riverton		Saltair Salt Plant		Utah Lake Lehi	
Elevation (ft)	4490		4470		4570		4660		4210		4500	
Begin Date	07/01/48		04/08/52		04/01/81		10/01/65		05/08/56		07/02/48	
End Date	10/30/51		09/24/60		10/31/92		09/30/68		08/31/91		08/31/92	
Years of Record	4		9		12		4		36		45	
Coverage (%)	67		54		65		51		63		59	
Miles from BCM	37		37		37		14		14		24	
Direction	SE		SE		SE		ESE		NW		SE	
Evaporation	Pan	Lake	Pan	Lake	Pan	Lake	Pan	Lake	Pan	Lake	Pan	Lake
Jan												
Feb												
Mar	2.85	2.00			2.59	1.81			3.69	2.58	2.66	1.86
Apr	6.03	4.22	4.28	3.00	4.85	3.40	5.59	3.91	6.21	4.35	5.13	3.59
May	6.83	4.78	5.95	4.17	6.84	4.79	7.46	5.22	9.09	6.36	7.28	5.10
Jun	8.62	6.03	7.22	5.05	8.84	6.19	8.48	5.94	11.88	8.32	8.91	6.24
Jul	8.88	6.22	8.32	5.82	9.78	6.85	10.71	7.50	14.35	10.05	9.76	6.83
Aug	8.37	5.86	7.34	5.14	8.62	6.03	9.99	6.99	12.67	8.87	8.71	6.10
Sep	6.09	4.26	5.28	3.70	5.41	3.79	7.14	5.00	8.50	5.95	6.18	4.33
Oct	3.41	2.39	3.26	2.28	2.87	2.01	5.14	3.60	4.86	3.40	3.77	2.64
Nov			1.33	0.93					2.14	1.50	1.43	1.00
Dec												
Total	51.08	35.76	42.98	30.09	49.80	34.86	54.51	38.16	73.39	51.37	53.83	37.68

All evaporative depths are in inches
Pan coefficient of 0.7 used to convert pan evaporation to lake evaporation

Maximum leaf-area indices, based on growing season length and annual rainfall amounts, are contained within the climatological data base which is part of the HELP model. The maximum leaf-area index for Salt Lake City (without irrigation) is reported to be 1.6 which is slightly less than the value of 2.0 which indicates "fair grass" as a cover crop. Therefore, as a conservative assumption, vegetation selected for this modeling exercise was "poor grass" and 1.0 was used as the maximum leaf-area index. It should be emphasized that the term "poor grass" is related to HELP terminology and is not indicative of the ability to develop an acceptable reclaimed surface on the waste dumps. The default growing season for Salt Lake City was used. For modeling purposes, the growing season is 163 days long, begins on May 1 and ends on October 11 (leaf-area index of 0.0 until May 1 when it begins increasing to the maximum of 1.0 sometime during the growing season based on daily temperature and solar radiation data and then declines to 0.0 on October 12).

2.2 Soils

As discussed in the Appendix, the user must select appropriate default HELP soils based on textural class or provide estimates of porosity, field capacity, wilting point and saturated hydraulic conductivity for each soil layer considered in the cover. Two reports regarding soils in the vicinity of the Barneys Canyon Mine were reviewed in an effort to select soil types which are likely to exist after reclamation is completed. Natural topsoils in the vicinity of the mine, as cataloged by JBR Consultants Group (1993), are summarized in Table 4. In general, the natural soils tend to be shallow, gravelly loams with low water holding capacity. Based on this data, default HELP soil 6 is considered most similar to natural soils observed in the Barneys Canyon area. The ability to amend waste rock with sewage sludge or other organic matter is being evaluated at the present time by Barneys Canyon. For modeling purposes, it was assumed that the soil cover will ultimately be similar in nature to the natural topsoils reported by JBR Consultants Group (1993) so that HELP soil 6 was also selected for use as the rooting zone soil obtained by organically amending waste rock.

In late 1993, a preliminary characterization of in-place waste rock was performed by HBT AGRA Limited. Field measurements and soil samples were collected at two existing waste dump locations—the 6500 Dump and the SBCS Dump. Parameters of interest to the modeling study include texture, porosity, saturated hydraulic conductivity, and field capacity. The dump materials were generally classified as sandy gravels. Pertinent data reported by HBT AGRA Limited (1994) are summarized in Table 5. In general, the "loose" material as described in the HBT AGRA report appears to be texturally similar and has porosity and permeability characteristics which roughly correspond to HELP default soil 1. Reported field capacities are much higher than normally encountered in sandy soils. Based on the discussion in HBT AGRA Limited (1994) and conversations with Kennecott personnel, it is probable that the field capacity samples were collected too soon after saturation.

TABLE 4
SUMMARY OF SOILS AT BARNEYS CANYON

Soil Series	AWHC (in/in)	Quality	Texture	Mean Depth (in)
Alluvial	- -	Excellent	Silt and Clay loams	42
Agassiz	0.10 - 0.12	Poor	Gravelly loam	10
Bradshaw	0.07 - 0.10	Poor	Gravelly/cobbly silt loam	20
Daybell	0.09 - 0.10	Fair	Gravelly silt loam	12
Fitzgerald	0.06 - 0.08	Fair	Gravelly loam	18
Gappmayer	0.08 - 0.10	Poor	Very gravelly silt loam	20
Wallsburg	0.05 - 0.10	Unsuitable	Cobbly silt loam	0

According to the report, the field capacity samples were collected after permeability testing was completed and the surface water had drained away. Typically, field capacity is defined as the water content remaining in the soil two to three days after a thorough irrigation. Soil permeability was determined using the ring-infiltrometer method. Compacted surface dump samples had hydraulic conductivity values in the range of 10^{-5} to 10^{-4} cm/sec while the hydraulic conductivities of the loose dump samples were typically greater than 10^{-3} cm/sec.

Based on the descriptions provided by HBT AGRA Limited (1994), it was concluded that default HELP soil 1 is probably most representative of subsoils which will exist in the upper levels of the waste dumps after surface preparation for vegetation seeding. This soil is described as a coarse sand and has a low water holding capacity and a high permeability. It is also considered appropriate as subsoil for the natural soils based on the descriptions provided by JBR Consulting Group (1993). Because imported topsoils or organically amended waste rock derived soils are expected to have more available water than HELP soil 1 (organic matter and improved soil structure are expected to enhance the water holding capacity), default HELP soil 6 was used for the rooting zone layer of the soil covers. Selected modeling runs were also performed using default HELP soil 9, considered similar to the alluvial soil reported by the JBR Consulting Group (1993) on the basis of texture, as the rooting zone layer.

The two HELP barrier soils, 16 and 17, were also utilized in the modeling study to evaluate the effect of including a barrier layer within the cover design. Soil parameters for the default HELP soils selected for the modeling study are summarized in Table 6. Key parameters used in the HELP modeling exercises are summarized in Table 7.

TABLE 5
SUMMARY OF WASTE DUMP DATA (AGRA, 1994)

Sample ID	Description	Density (lb/ft^3)	Moisture Content		Void Ratio	Saturated Hydraulic Conductivity (cm/sec)	Saturation at Field Capacity (%)	Porosity	Volumetric Field Capacity
			Initial (%)	Field Capacity (%)					
6500-A	Trench at 15′	138.6	10.5	17.1	0.27	1.3×10^{-5}	163	0.213	--
6500-B	Trench at 10′	139.5	7.2		0.22	2.2×10^{-5}	--	0.180	--
6500-C	Trench at 8′	136.4	6.5	8.9	0.25	1.0×10^{-4}	92.6	0.200	0.185
6500-D	Trench at 0′	131.5	4.2	9.1	0.27	2.0×10^{-4}	87.5	0.213	0.186
6500-E	Surface-Compacted	133.0	5.0		0.26	--	--	0.206	--
6500-F	Surface-Loose	114.1	5.8	9.6	0.48	fd	51.1	0.324	0.166
6500-G	Surface-Loose	120.0	4.1	7.1	0.38	$>10^{-3}$	48	0.275	0.132
SBCS-A	Surface-Compacted	113.6	6.0	16.2	0.31	--	117	0.237	--
SBCS-B	Surface-Compacted	120.8	9.9	14.3	0.27	7.4×10^{-6}	118	0.213	--
SBCS-C	Surface-Loose	81.8	7.8	14.0	0.85	fd	36.8	0.459	0.169
SBCS-D	Surface-Semi Compacted	97.4	9.4		0.57	3.4×10^{-5}	--	0.363	--

Notes: fd - conductivity was listed as free draining. Porosity calculated based on void ratio: $n = e/1+e$. Volumetric field capacity calculated based on saturation at field capacity and porosity: $\theta_{fc} = (S_{fc}(\%)*n)/100$.

TABLE 6 SUMMARY OF SELECTED HELP MODEL SOILS					
Parameter	Soil 1	Soil 6	Soil 9	Soil 16	Soil 17
USDA Description	CoS	SL	SiL	Liner Soil	Liner Soil
Porosity (vol/vol)	0.417	0.453	0.501	0.430	0.400
Field Capacity (vol/vol)	0.045	0.190	0.284	0.366	0.356
Wilting Point (vol/vol)	0.018	0.085	0.135	0.280	0.290
Saturated Hydraulic Conductivity (cm/sec)	1.0×10^{-2}	7.2×10^{-4}	1.9×10^{-4}	1.0×10^{-7}	1.0×10^{-8}

TABLE 7
SUMMARY OF KEY PARAMETERS USED IN HELP MODELING

Climatic data	Synthetic precipitation, temperature and radiation data generated by HELP model based on coefficients for Salt Lake City; for sensitivity, precipitation adjusted upward by about 10%; monthly average values of temperature and precipitation used in simulations are listed below:

Month	Temperature (°F)	Default Precipitation (inches)	Adjusted Precipitation (inches)
Jan	28.6	1.42	1.07
Feb	34.1	1.09	0.95
Mar	40.7	1.46	1.80
Apr	49.2	1.88	1.29
May	58.8	1.14	1.55
Jun	68.3	1.04	0.61
Jul	77.5	0.99	1.65
Aug	74.9	0.93	1.27
Sep	65.0	1.14	1.96
Oct	53.0	0.95	1.38
Nov	39.7	1.21	1.81
Dec	30.3	1.43	1.27
Annual	51.7	14.68	16.61

Evaporative Zone Depth	24 inches
Vegetative Cover Type	"Poor Grass" (as defined by HELP model)
Maximum Leaf Area Index	1.0 (Recommended value for "poor grass"; maximum expected for Salt Lake City is 1.60 without irrigation)
Growing Season Start	May 1
Growing Season End	October 11
Growing Season Length	163 days

3.0 RESULTS

As discussed in the introduction, two types of cover systems were evaluated for the Barneys Canyon Mine. A cover system which relies on evapotranspiration rather than barrier layers to minimize infiltration is considered appropriate for the oxide waste dumps. For the sulfide waste rock, barrier layers were considered since the potential for environmental impact due to infiltration is somewhat larger. The results of the HELP modeling for each cover conceptualization is provided in the following subsections. The modeling performed with UNSAT2 to verify the results obtained with the HELP model is presented in the third subsection.

3.1 Oxide Waste Cover System

The current reclamation plan for the waste dumps is to place about 12 inches of topsoil over the waste rock and revegetate the surface. This tentative design was taken as Oxide Scenario 1 and, for modeling purposes, was assumed to consist of 12 inches of HELP soil 6 and 12 inches of HELP soil 1. Based on the twenty year synthetic weather record, the HELP model predicts that the percolation losses through such a cover is about 0.7 inch per year. To demonstrate the effects of increased water holding capacity, Oxide Scenario 2 consisting of 12 inches of HELP soil 9 (alluvial soil) and 12 inches of HELP soil 1 was modeled. The predicted percolation loss through this cover is about 0.5 inch per year.

Test plot studies currently underway at the site include waste rock amended with 10 tons of sewage sludge per acre. The sludge was mixed into the upper six inches of the soil so that the organic content of the soil was increased by 0.5 percent or more. Although it is likely that a greater actual depth of well structured soil will be obtained after reclamation (through a combination of organic matter amendment, tillage practices during reclamation, and ongoing plant growth), a worst-case analysis was performed as Oxide Scenario 3. To model Oxide Scenario 3, a cover consisting of 6 inches of HELP soil 6 and 18 inches of HELP soil 1 was evaluated. The predicted percolation loss from the cover was estimated to be about 1.1 inch per year for the 20 year synthetic weather data.

As implied by comparison of results for Oxide Scenarios 1 and 2, maximizing the water holding capacity of the soil is probably the best way to reduce percolation through the root zone. Oxide Scenario 4, in which it was assumed that addition of organic matter and tillage could be utilized to obtain an amended waste rock plant growth media over the entire evaporative zone depth, was also evaluated. For modeling purposes, this cover consisted of a single, 24 inch layer of HELP soil 6. Predicted percolation was reduced to about 0.4 inch per year for this case.

The effect of higher annual precipitation was evaluated as Oxide Scenario 5 by increasing the precipitation from 14.7 inches to 16.6 inches (about 10%) with a distribution similar to that observed at the Bingham Geology station and running the model for the same cover system as described for

TABLE 8 SUMMARY OF HELP MODELLED OXIDE COVER ALTERNATIVES					
Oxide Scenario	1	2	3	4	5
Cover Condition Evaporative Depth (in) SCS Curve Number	Poor Grass 24 80	Poor Grass 24 87	Poor Grass 24 80	Poor Grass 24 80	Poor Grass 24 80
Layer 1	12in soil#6	12in soil#9	6in soil#6	24in soil#6	24in soil#6
Layer 2	12in soil#1	12in soil#1	18in soil#1	N/A	N/A
Precipitation (in/yr) Runoff (in/yr) ET (in/yr) Δ storage (in/yr) Percolation (in/yr) Peak Daily Perc (in)	14.68 0.006 13.919 0.050 0.7022 0.5155	14.68 0.062 13.989 0.054 0.5716 0.5425	14.68 0.005 13.520 0.039 1.1144 0.6991	14.68 0.006 14.203 0.074 0.3951 0.1896	16.62 0.022 16.090 0.039 0.4644 0.1175

Oxide Scenario 4 in the previous paragraph. The predicted percolation under these conditions is estimated to be about 0.46 inch per year or just slightly more than the 0.4 inch predicted with the original precipitation data. Model results obtained for the various cover systems considered most likely to exist on completion of reclamation are summarized in Table 8.

Several computer runs were performed to evaluate the sensitivity of the model to various parameters. In general, the results indicate that a deep percolation rate of less than 2 inches can be expected even under the worst of conditions—that is, for a soil with a low water holding capacity (HELP soil 1). Review of the daily output for selected runs indicates that percolation losses are most likely to occur in the winter and early spring when water from snowmelt is readily available and evaporative demands are lowest. For example, the daily record for the cover design consisting of 24 inches of HELP soil 6 indicates that deep percolation events occur in only four of the twenty years evaluated. For three of the events, recharge began in February and persisted until mid-July. The fourth recharge event began in April and persisted until mid-July. These observations reinforce the conclusion that maximizing the storage capacity of the root zone layer is critical in minimizing the amount of deep percolation loss from the cover.

3.2 Sulfide Waste Cover System

Although the conceptual cover designs for the oxide waste dumps indicate that vegetation is relatively effective in minimizing deep percolation, the possibility of further reducing percolation into sulfide waste rock was investigated. Based on results of the oxide cover analyses, it is likely that a low permeability (barrier) layer will be necessary to achieve this goal. Results of the oxide cover analyses indicate that percolation rates of an inch per year or less are likely without the addition of a barrier layer. Therefore, the permeability of the cover will need to be less than an inch per year (approximately 10^{-7} cm/sec) to be effective. Results of the analyses of conceptual sulfide waste cover system designs are summarized in Table 9.

The initial cover evaluated with the HELP model (Sulfide Scenario 1) consisted of 12 inches of topsoil/amended waste rock (HELP soil 6), 30 inches of subsoil (HELP soil 1) and a barrier layer consisting of 12 inches of clay with a permeability of 10^{-7} cm/sec (HELP soil 16). For this scenario, the subsoil layer was not specified as a lateral drainage layer. The predicted deep percolation of about 0.7 inch per year is the same as predicted for a similar cover without the barrier layer which confirms that little benefit is gained by incorporating a 10^{-7} cm/sec layer in the cover. In Sulfide Scenario 2, the subsoil layer was specified as a lateral drainage layer with a drainage slope of 2% over 300 feet. The resulting deep percolation was reduced to about 0.4 inch per year. This comparison demonstrates the need to include lateral drainage layers in the cover design. By increasing the slope of the drainage layer to 10% (Sulfide Scenario 3), the predicted percolation rate was reduced to 0.2 inch per year.

The next series of modeling runs were performed with similar cover designs but the permeability of the barrier layer was decreased to 10^{-8} cm/sec (HELP soil 17). For designs consisting of 12 inches of HELP soil 6 and 30 inches of HELP soil 1 configured as a drainage layer, the model predicts percolation rates of about 0.09 inches for barrier thicknesses of 12 inches (Sulfide Scenario 4) or 9 inches (Sulfide Scenario 5). In fact, reducing the barrier layer thickness to 3 inches (Sulfide Scenario 6) resulted in a percolation estimate of 0.11 inch per year. These results demonstrate that the barrier layer does not need to be thick to be effective if water which percolates past the root zone can be drained from the top of the barrier layer. Increasing the slope of the lateral drainage layer to 10% (Sulfide Scenario 7) resulted in a predicted percolation rate of about 0.04 inch per year. For Sulfide Scenario 8, the thickness of the lateral drainage layer was reduced to 12 inches, which in effect extends the evaporative zone to the top of the barrier layer, resulted in a predicted percolation rate of 0.03 inch per year. Sulfide Scenario 9, the final cover evaluated for the sulfide waste repository, consists of 12 inches of HELP soil 9 (alluvial soil), 24 inches of HELP soil 1 (sandy subsoil) defined as a lateral drainage layer, and 3 inches of HELP soil 17 (barrier layer). The predicted percolation rate for this scenario is also 0.03 inch per year.

3.3 UNSAT2 Verification

In an effort to determine if limitations of the HELP model have any effect on the predicted percolation rates, the UNSAT2 model was used. Because of the difficulty in setting up the UNSAT2 model for simulations over a 20 year period, it was applied only for a relatively short time period when conditions favoring the development of capillary barriers are most likely. For comparison purposes, the

TABLE 9
SUMMARY OF HELP MODELLED SULFIDE COVER ALTERNATIVES

Sulfide Scenario	1	2	3	4	5	6	7	8	9
Cover Condition Evap. Depth (in) SCS Curve Number	Poor Grass 24 80	Poor Grass 24 80	Poor Grass 24 80	Poor Grass 24 80	Poor Grass 24 80	Poor Grass 24 80	Poor Grass 24 80	Poor Grass 24 80	Poor Grass 24 87
Layer 1	12in #6	12in#6	12in #6	12in #6	12in #6	12in #6	12in #6	12in #6	12in #9
Layer 2 Drain Slope (%) Drain Length (ft)	30in #1 N/A N/A	30in #1 2 300	30in #1 10 300	30in #1 2 300	30in #1 2 300	30in #1 2 300	30in #1 10 300	12in #1 10 300	24in #1 10 300
Layer 3	12in #16	12in #16	12in #16	12in #17	9in #17	3in #17	3in #17	3in #17	3in #17
Precipitation (in/yr) Runoff (in/yr) ET (in/yr) Drainage (in/yr) Δ storage (in/yr) Percolation (in/yr) Peak Daily Perc (in)	14.68 0.006 13.919 N/A 0.050 0.7022 0.0058	14.68 0.006 13.919 0.3124 0.050 0.3988 0.0050	14.68 0.006 13.919 0.5010 0.050 0.2012 0.0044	14.68 0.006 13.919 0.6173 0.050 0.0851 0.0005	14.68 0.006 13.919 0.6149 0.050 0.0874 0.0006	14.68 0.006 13.919 0.5969 0.051 0.1055 0.0010	14.68 0.006 13.919 0.6596 0.051 0.0428 0.0007	14.68 0.006 13.912 0.6758 0.051 0.0337 0.0008	14.68 0.062 13.989 0.5414 0.054 0.0306 0.0007

cover design selected for evaluation consisted of 24 inches of amended waste rock (HELP soil 6) underlain by 24 inches of sandy subsoil (HELP soil 1). The model was run for a 31 day period beginning on January 22 of the fifteenth year.

According to the HELP model output, the period selected for UNSAT2 verification modeling represents the peak percolation rate during the 20 year simulation period. The initial date selected was about 10 days prior to initiation of deep percolation according to the HELP daily output. Soil hydraulic properties utilized in the UNSAT2 modeling were similar to those used in the HELP modeling:

	Topsoil	Subsoil
Porosity	0.453	0.457
Residual Water Content	0.031	0.019
Pore-size Distribution Index	0.3001	0.8715
Bubbling Pressure Head, cm	12.58	13.45
Saturated Hydraulic Conductivity, cm/sec	1.3×10^{-4}	1.0×10^{-2}

Topsoil initial conditions for the UNSAT2 model were based on water contents computed by the HELP model at the end of the previous day. A comparison of the initial conditions for the two models is provided on Figure 1. As shown, water contents of about 0.32 occurred from the soil surface to a depth of about 15 inches below which the soil becomes drier and reaches the wilting point water content of 0.085 at the bottom of the root zone. In the subsoil, the initial water content was set at about field capacity, 0.045, which is about the water content which would exist for downward flow under a unit gradient and a percolation rate of 0.40 inch/year.

One-dimensional vertical flow was considered with the UNSAT2 model so that lateral migration of moisture was prevented. The finite element mesh consisted of 276 nodes and 137 elements with the maximum distance between nodal points limited to 1 cm and the minimum distance (at the soil surface and the interface between the two soils) was set to 0.1 cm. An infiltration/evaporation boundary was applied to the surface of the soil column and impermeable boundaries were applied along all other boundaries of the soil column. Due to the fact that the analysis period occurs prior to initiation of the growing season, it was not necessary to invoke the root uptake option of UNSAT2. Because water could not leave the flow region, percolation losses were computed by calculating the change in water stored in the subsoil at the end of each day.

To be consistent, precipitation amounts were taken from the daily output from the HELP model. According to the HELP daily output, runoff occurred only on one day during the simulation period (0.066 inch on February 5) so that the precipitation depth for that date was taken as the difference in precipitation (1.12 inch) and runoff. The UNSAT2 model requires that the duration of each event be known so a storm duration of four hours was selected for all events except the February 5 event

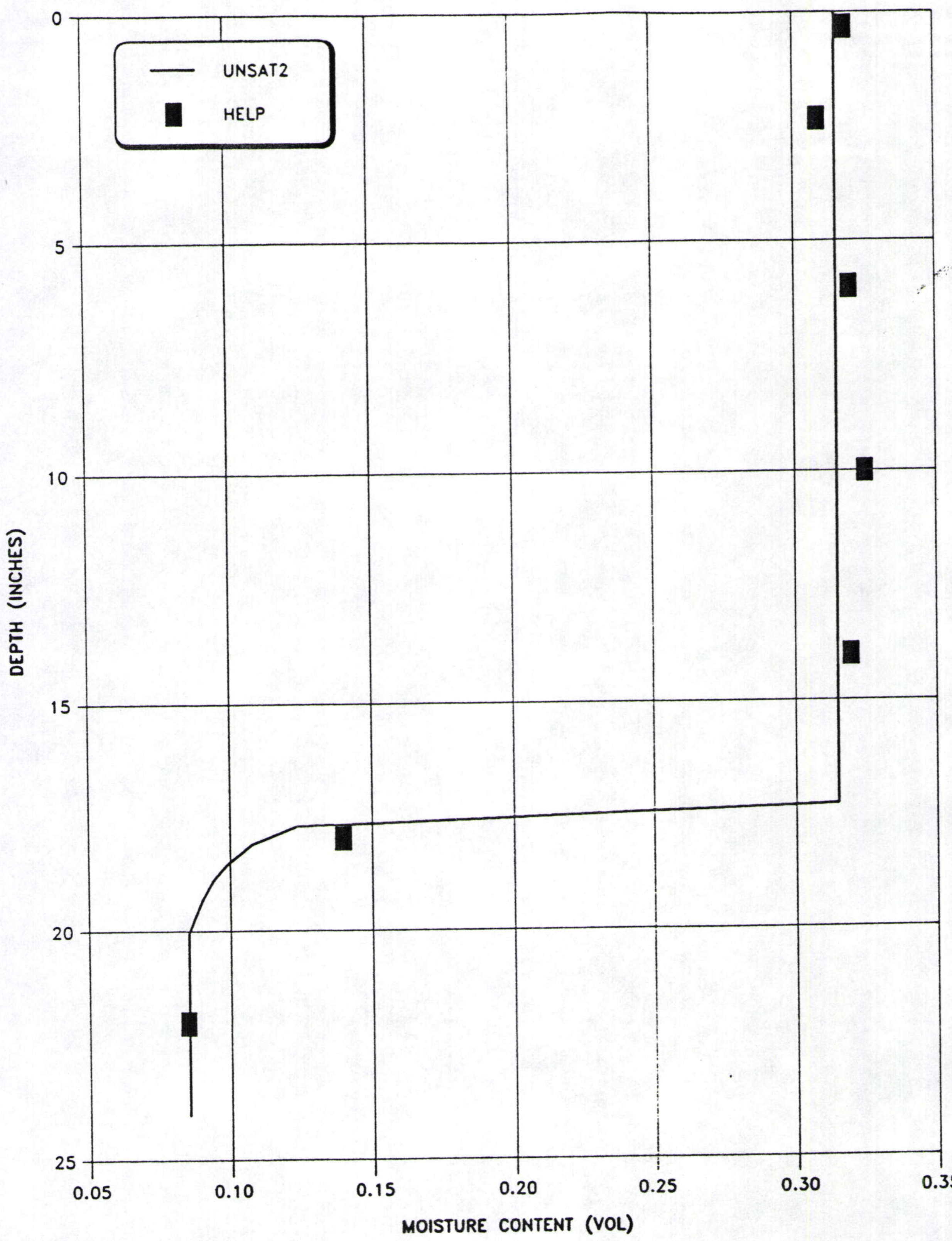

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FIGURE 1
COMPARISON OF UNSAT2 INITIAL CONDITIONS WITH HELP OUTPUT

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which was assumed to last 12 hours. This approach ensured a rainfall intensity of less than the saturated hydraulic conductivity of the topsoil which ensured that all precipitation would infiltrate into the soil cover.

The evaporative potential at the soil surface was estimated by computing potential evaporation with the Jensen-Haise (1963) method based on climate data for Salt Lake City. The result was divided by 0.7 to convert it to pan evaporation which is appropriate as an estimate of the evaporative potential at the soil surface. The soil evaporative potential for January and February were estimated to be about 0.047 inch/day and 0.062 inch/day, respectively. Within each month, the soil evaporative potential was held constant on dry days. On days when the precipitation depth exceeded 0.01 inch, the soil evaporative potential was reduced by a factor of two.

The computations were performed with a minimum time step of about 0.1 second, a maximum time step of 1 hour, and a time step multiplier of 1.3. A total of 1161 time steps were required to complete the 31 day simulation. The total infiltration into the soil profile during the simulation was 2.06 inches (same as for the HELP model) while total soil evaporation was 3.51 inches which compares reasonably well with the HELP total of 3.74 inches. Total water stored in the root zone at the end of the simulation was 5.93 inches compared to 6.03 inches for the HELP model. Percolation as a function of time for the two models is compared on Figure 2. The HELP model predicted that percolation would begin on about February 1 (11 days) while UNSAT2 predicted that percolation would not begin until the 15th day (February 5). As Figure 2 demonstrates, the UNSAT2 peak percolation of about 0.04 inch/day occurred slightly before the HELP peak percolation of about 0.07 inch. The total percolation according to the UNSAT2 model was about 0.38 inch while the HELP model predicted a percolation of about 0.62 inch during the same period. It should be noted, however, that the slope of the percolation versus time curve for UNSAT2 is not as steep as that for the HELP model. Therefore, the total percolation volumes would tend to become closer in value if the UNSAT2 simulation were carried out over a longer time period. *Nonetheless, it would appear that the HELP model does slightly overpredict percolation losses as concluded by other researchers.*

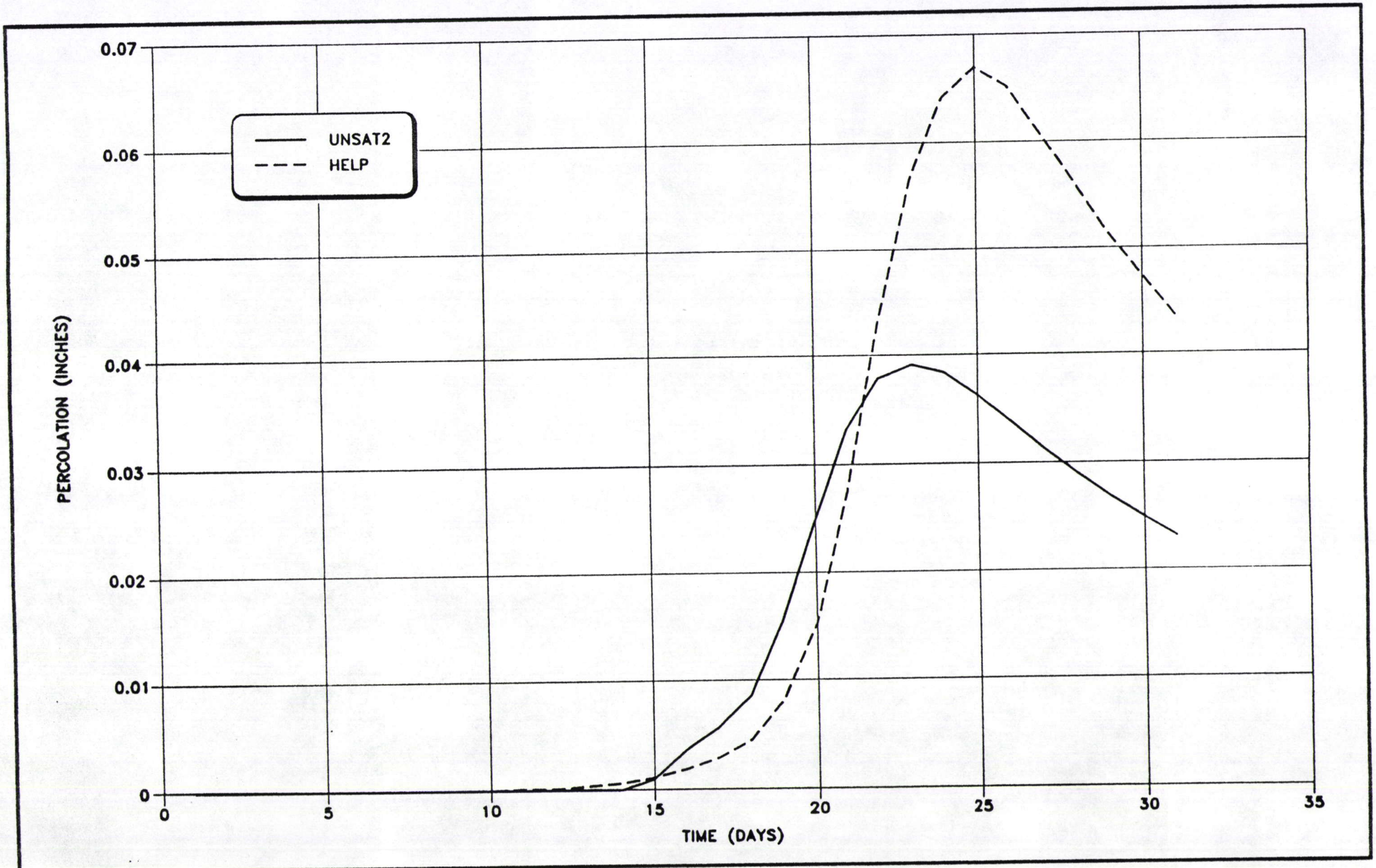

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FIGURE 2
COMPARISON OF MODELED PERCOLATION RATE

Date: APR 1994

Project: 94207

4.0 RECOMMENDATIONS

Based on the modeling performed during this study, recommended designs for cover systems for the two types of waste rock have been developed. The conceptual designs for each cover system are described in the following subsection. A limited risk assessment regarding the stability of the cover systems is provided in the third subsection and discussion regarding methods which may be used to verify percolation in waste dumps is provided in the fourth subsection.

4.1 Oxide Waste Dump Cover Design

For the oxide waste dumps, it is concluded that an adequate cover system can be developed through revegetation of the reclaimed surface of the waste piles. Based on the test plot studies being performed at Barneys Canyon, it appears that an adequate plant growth media can be developed by amending the waste rock material with sewage sludge or other organic material. It is recommended that the upper 24 inches of the dump be amended with organic rich material to enhance the structure and water holding capacity of the soil. Once vegetation is established, natural processes are expected to continue to increase the organic matter content in the soil until equilibrium conditions are achieved. It is estimated that the deep percolation rate for these covers will be less than an inch per year with 0.4 inch per year representing the most probable average value.

4.2 Sulfide Waste Dump Cover Design

If very low percolation rates are desired (on the order of 0.1 inch per year or less), the base of the cover system should consist of a barrier layer to inhibit seepage from the waste. Although the modeling indicates that three inches of clay with a permeability of 10^{-8} cm/sec is essentially as effective as one foot of clay, it is probably quite difficult to construct such a thin barrier layer and ensure its quality. Therefore, it is recommended that the barrier layer be constructed in two lifts with thicknesses of four to five inches. While it would increase the confidence in the barrier layer to compact both lifts to specification for a permeability of 10^{-8} cm/sec, an adequate barrier layer could be obtained by compacting one lift to a permeability of 10^{-7} cm/sec and one lift to a permeability of 10^{-8} cm/sec. Alternatively, an artificial barrier layer (e.g. flexible membrane liner) could be employed as long as the permeability of 10^{-8} cm/sec (or less) can be achieved.

The surface of the barrier should be sloped at 10% or greater to facilitate drainage of water which may build up above the barrier layer. A coarse sand layer about 12 inches thick should be placed above the barrier layer to promote lateral drainage. A filter blanket should be designed and placed above the lateral drainage layer to minimize migration of fine grained soil materials into the drainage layer. The final design of the filter blanket should be based on gradation of the drainage layer and the plant growth media which forms the uppermost layer of the cover. The sulfide material repository should be designed to allow drainage from the sand layer to be discharged off the cover at its edges. The longest distance from the center of the waste pile to the discharge location should ideally be less than 500 feet.

Although the modeling results indicate that inclusion of lateral drainage and barrier layers in the cover system will be effective in reducing percolation into the waste rock, a viable vegetative cover is considered an important component of the cover. To this end, it is recommended that topsoil similar to the alluvial material available on site be placed to a total thickness of 24 inches as the uppermost layer of the cover system. Although it is not essential that actual alluvial soil be used, the selected topsoil should have water retention characteristics that are similar to those of the alluvial material (in general, less sand and more silt and clay than in the waste rock) to maximize water available for plant use. Management practices (e.g. incorporation of additional organic matter) which are considered necessary to assure rapid initiation of plant growth and long-term success of a viable plant community on the reclaimed surface should be implemented. It is believed that a cover constructed in this manner will limit percolation into the sulfide waste material to less than 0.1 inch per year.

4.3 Risk Evaluation

The predictions of infiltration and deep percolation for the cover designs assume that water will not be allowed to pond on the surface of the reclaimed waste dumps. To ensure that ponding does not occur, the reclamation surface should be graded in a manner to promote runoff. Over the long-term, settlement and erosion have the potential to change grades leading to ponded water which would increase the amount of water percolating through the dump.

Based on discussions with Barneys Canyon Mine personnel, the waste dumps tend to consolidate reasonably well during construction and subsequent settlement is expected to be minimal. Care should be exercised when regrading the dumps during reclamation to ensure that fill materials are placed in such a manner that will minimize subsequent settlement that could lead to the formation of low spots or flat grades. Possible measures which could be utilized to ensure minimal settlement include compacting regraded material to achieve an in place density that is similar to the density of existing waste dumps or designing the top slope to be sufficiently steep that positive drainage will be maintained as the regraded waste consolidates.

The surface of reclaimed waste dumps should be graded to force runoff to occur as sheet flow over the entire surface. The final cover should be free of depressions, swales or other features that could lead to concentration of flow and subsequent erosion of the waste dump cover. If it is not possible to maintain uniform slopes, provisions for control of concentrated flow should be invoked. In such cases, it will be necessary to estimate peak flows and design erosionally stable diversion channels for those flows. Because these will probably need riprap protection, every effort should be made to eliminate the need for such structures because the riprap will act as a mulch which will inhibit evaporation.

While construction activities, such as those described above, can be developed to ensure that the reclamation covers are built so as to minimize the potential for ponding, an inspection program should be initiated to identify potential problems during the first few years following completion of reclamation. Inspections should initially be performed on a monthly basis for the first year. After that the frequency can be reduced to about once per quarter and after major precipitation events over the next two years. Appropriate repairs should be implemented as needed to minimize the potential for ponding of water on the reclaimed surface.

4.4 Verification of Performance

One of the secondary objectives of this study was to develop a method by which the predictions of deep percolation through the waste dumps could be verified. A direct measurement of the percolation is considered the ideal way to verify model results. Unfortunately, such measurements are difficult, particularly in arid environments where the deep percolation component is small. Methods considered for the Barneys Canyon waste dumps are presented in the following paragraphs.

Originally, it was believed that a bucket lysimeter could be installed within the waste dump as it was constructed. This device basically consists of a trough in which downward percolating water is captured. The base of the trough is sloped to an outlet which drains to a collection jar (the bucket). The volume of water in the jar is measured periodically and the percolation rate is computed by dividing the volume by the area of the trough. The sides of the trough must extend a sufficient distance above the base to ensure that the device does not cause convergence or divergence of flow through the pile.

Although such a device could be designed and implemented, the length of time necessary to evaluate performance would be long and the potential for obtaining false data is considered high. For a trough with a size of 10 feet by 10 feet, a total of about 8.3 cubic feet of water would be captured during a year if the percolation rate is 1 inch per year. Water will not flow from the device until the soil near the base becomes saturated (that is, after a perched water table is developed). The length of time for soil moisture within the device to come to equilibrium is difficult to predict. However, based on results of the HELP modeling, little or no deep percolation may occur in dry years. In the event that dry weather prevails after installation of the device, it could be several years until equilibrium conditions are achieved. On the other hand, if wet conditions prevail and the waste rock is placed at moisture contents that are higher than the equilibrium moisture content, the drainage could make it appear that the percolation rates are greater than they actually are. For these reasons, data would need to be collected for a considerable number of years (20 or more) to have enough data to statistically quantify the percolation rate. It would also be necessary to collect detailed weather data during this time to allow the percolation rate to be compared to precipitation. Given these considerations, the bucket lysimeter does not appear to be a practical method for verification of predicted percolation rates over the short-term. However, bucket lysimeters could be installed to provide an indication as to whether the percolation predictions are reasonably correct or considerably in error. Data obtained should be carefully evaluated in an effort to ensure that the inherent limitations of the device have not unduly influenced the results.

Because the percolation rates are expected to be small, traditional methods (e.g. tensiometers or neutron probes) of estimating moisture content and computing flux probably will not work. For conditions of steady downward flow under a unit gradient, low flux rates are synonymous with high capillary pressures. The capillary pressures that typically exist exceed the bubbling pressure of ceramic tensiometer cups causing them to desaturate so that measurement of the capillary pressure in the soil is not possible. For tensiometers to be effective in estimating flux, the hydraulic properties of the soil in contact with the cup must be known. Because these may change over time, it may not be possible to estimate flux even if measuring capillary pressure was possible. Estimating moisture content with the neutron method is fraught with difficulties (changing hydraulic properties, instrument calibration, etc.) so this method is not considered a realistic alternative for verification at Barneys Canyon.

It is possible that an indirect method of validating the model can be utilized. The recharge rate in natural materials in the vicinity of the waste dump areas could be determined with the chloride mass balance method described by Allison and Hughes (1978). Soil cores would have to be collected and the chloride concentration determined through laboratory analyses. In addition, the hydraulic properties required by the HELP model (porosity, field capacity, wilting point and hydraulic conductivity) would need to be determined for the soils within the root zone. The HELP model would then be applied to the natural system and the predicted percolation compared with the recharge computed with the chloride mass balance. This would provide a factor which could then be applied to HELP model results for the reclamation covers. Unfortunately, this approach to verification also has limitations. The most severe is associated with the need to accurately determine the chloride content of precipitation. While maps which depict precipitation chloride content as a function of distance from the ocean (the chloride source) have been published, it would be necessary to collect additional site specific data, particularly in view of local weather patterns and the potential effects of the Great Salt Lake. Monitoring would have to be conducted over several years to ensure that true average values are obtained. Because surface runoff is probably an important component of the overall water balance, it would also be necessary to determine runoff volume and chloride content for use in the chloride mass balance. Given the long time frame required for data collection and potential inaccuracies in measuring some of the components (e.g. runoff volume), this method is unlikely to be any better than using the bucket lysimeter approach described previously.

APPENDIX

DESCRIPTIONS OF MODELS UTILIZED

A.1 HELP Model

The HELP (Hydrologic Evaluation of Landfill Performance) model was developed to facilitate rapid evaluation of various landfill designs in a variety of climatologic and hydrologic regimes. It was developed primarily to allow designers to compare the performance of alternative landfill cover designs and not for use in developing predictions of the quantity of water moving through a particular cover design. While not originally intended as a method for quantifying the amount of percolation through a composite cover system, results reported by Stephens and Coons (1994) suggest that the model provides reasonable estimates of recharge. The first version of the HELP model was released in 1984 (Schroeder, et al. 1984a and 1984b). The model utilized in this study is Version 2.05 which was released in late 1988 and is described in detail by Schroeder, et al. (1989).

To evaluate composite cover designs, the HELP model performs a water balance on the cover. The model uses daily climatologic data consisting of precipitation, temperature and solar radiation to predict the amount of runoff, evapotranspiration, lateral drainage, deep percolation and change in soil moisture storage within the cover which occurs during the day. The runoff submodel is based on the well-known curve number method developed by the U.S. Soil Conservation Service (SCS) but uses computed soil moisture contents to adjust the curve number according to antecedent moisture conditions (the curve number is increased for wet conditions and decreased for dry conditions). Evaporation from the soil surface and transpiration from plants are modeled using empirical methods that estimate the potential evapotranspiration for each day based on the climatic data. The evapotranspiration submodel includes a vegetative growth model which computes daily values of the leaf-area index based on a maximum value, daily temperature and solar radiation data, mean monthly temperatures and the beginning and ending dates of the growing season. Lateral drainage is approximated as steady flow toward parallel drains assumed to exist at the edge of the landfill. Deep percolation, W, is computed as the residual of precipitation after accounting for the above described losses:

$$W = P - Q - L - E_t - \Delta S \tag{1}$$

where P is precipitation, Q is runoff, L is lateral drainage, E_t is evapotranspiration and ΔS represents the change in soil moisture storage. Within the cover, vertical movement of water is based on the Brooks-Corey (1964) equations.

One of the factors that makes the HELP model very easy to utilize is that it contains a relatively large data base of climatologic information. Included in the climatologic data base are coefficients used to generate a synthetic temperature and solar radiation data set for 184 cities located throughout the United States. Default evaporative depths for the various crop covers considered by HELP (bare ground, poor grass, fair grass, and excellent grass) are included in the data base. The HELP climatic data base also includes coefficients for 139 cities which can be used to generate a synthetic daily precipitation record. Default five year (1974 through 1978) historical data sets are also available for 102 U.S. cities. In lieu of utilizing the synthetic or default HELP climatologic data, the user can utilize a historic data set or data from a different weather generator provided that the data are formatted according to HELP requirements.

The HELP program also contains default soil characteristics categorized by soil textural class. The required soil characteristics are porosity, field capacity, wilting point and saturated hydraulic conductivity. The program contains these parameters for 15 soil textures (ranging from coarse sand to clay), 2 barrier soils (clays), and municipal waste. The default values for porosity were taken as the means from a data set consisting of 5,350 horizons of 1,323 soils from 32 states while the default values for saturated hydraulic conductivity are mean values for a "large data set." Because wilting point and field capacity are not widely reported in the literature, the default values were obtained in an indirect manner. The data set utilized for the porosity computations was used to calculate the mean values of the Brooks-Corey parameters—bubbling pressure (defined as the capillary pressure at which the air phase becomes continuous in a porous medium), pore size distribution index (a measure of the uniformity of pore sizes), and residual water content (the water content at which liquid water movement ceases)—for each textural soil class. For each textural class, field capacity and wilting point were then computed with the Brooks-Corey equation:

$$\theta = (n - \theta_r)\left[\frac{\psi_b}{\psi}\right]^{\lambda} + \theta_r \tag{2}$$

where θ is moisture content, n represents the saturated soil water content (porosity), ψ_b is the bubbling pressure, ψ is soil capillary pressure, λ represents the pore size distribution index and θ_r is the residual water content. To obtain the field capacity, θ_f, the capillary pressure, ψ, was set to 1/3 bar while to obtain the wilting point, θ_w, the capillary pressure, ψ, was set to 15 bars. The resulting wilting point water contents were used along with the mean residual water contents for each soil textural class to develop a regression equation relating the residual water content to the wilting point:

$$\theta_r = 0.253\theta_f + 0.014 \tag{3}$$

where θ_r is the residual water content and θ_f is the water content at field capacity.

As input, the user can specify default soils in which case the model selects the porosity, field capacity, wilting point and saturated hydraulic conductivity according to the textural class selected.

Alternatively, the user can specify these four parameters. In either event, the program then computes the residual water content with Equation 3. The bubbling pressure and pore size distribution index are computed by simultaneously solving the two equations obtained for Equation 2 by first setting θ to θ_f and ψ to 1/3 bar and then by setting θ to θ_w and ψ to 15 bars. The pore size distribution index is utilized to compute the Darcy flux, q, in the soil cover with the following equation:

$$q = K_s \left[\frac{(\theta - \theta_r)}{(n - \theta_r)}\right]^{3+2\lambda} \tag{4}$$

where K_s represents the saturated hydraulic conductivity and other symbols are as defined previously. This equation assumes a hydraulic gradient of unity. The bubbling pressure, which is not allowed to exceed 1/10 bar (103.34 cm of water), is used only to compute the hydraulic conductivity at 1/10 bar which is used in turn to compute the evaporation coefficient. The evaporation coefficient indicates the ease with which water can be drawn upward through the soil and is a function of the hydraulic conductivity at 1/10 bar. According to Ritchie (1972), the evaporation coefficient has a minimum of 3.3 mm/day$^{0.5}$ and a maximum of 5.1 mm/day$^{0.5}$ and the program does not allow values outside this range. It should be noted that the evaporative coefficient is an empirically derived parameter which accounts for the fact that cumulative evaporation from a soil surface increases as a function of the square root of time (thus, coefficient units of mm/day$^{0.5}$)

Design data required by the model includes the number of layers in the cover and, for each layer considered, a layer type, layer thickness, and soil texture (for default soils or soil parameters input by the user). The model allows four types of layers:

1. Vertical Percolation Layer: a layer of moderate to high permeability without drainage collection systems; only vertical percolation in response to unit gradient conditions is allowed in such layers (no lateral moisture migration); typically, the plant root zone is considered a vertical percolation layer.

2. Lateral Drainage Layer: a layer of moderate to high permeability permitting lateral drainage to collection systems or perimeter drains; both vertical unit gradient seepage and lateral quasi-steady state saturated migration are considered; only allowed above a barrier layer.

3. Barrier Soil Liner: a layer of material designed to inhibit percolation; typically low permeability (clay) soils; barrier layers are not allowed adjacent to one another

4. Barrier Soil Liner with a Flexible Membrane Liner: a composite barrier layer consisting of a soil liner with a membrane liner

Up to 12 separate layers can be specified for a cover design. When a lateral drainage layer is specified, the distance to the drain must be specified along with the cover slope in percent. The initial water content of each layer can also be specified by the user or it can be computed by the program. Similarly, the user can specify the SCS curve number or the program will compute it based on the soil parameters which are specified by the user.

Daily, monthly and/or summary output can be requested by the HELP user. Daily output includes depths of precipitation, runoff and evapotranspiration and the average moisture content within the evaporative zone. Percolation depth through each barrier layer or the base of the cover is also output. If lateral drainage layers are specified, the depth of water drained from the cover is included in the daily output. Monthly output consists of the monthly depths of precipitation, runoff, evapotranspiration, percolation through barrier layers and/or the base of the cover, and lateral drainage from the cap (if a lateral drainage layer is specified). The average head buildup within the lateral drainage layer is included in the monthly output. Summary output consists of the average monthly data as well as average daily values for each of the water budget parameters. Peak daily values of each parameter are also provided in the summary output.

While the HELP model is a useful tool in evaluating landfill performance, it also has a few limitations which should be noted. Because it is essentially a water balance model, computations are based on water content, and transient gradients and their effect on water movement are neglected. As a result, the potential for upward flow from beneath the root zone is not considered by the model. While this shortcoming is probably not important in humid climates, Stephens and Coons (1994) suggest that upward moisture movement may be important in arid climates. Neglecting upward flow within the evaporative zone is probably not important since the model utilizes the evaporation coefficient to approximate movement within the root zone. However, it should be emphasized that the HELP model does not allow water which has moved downward below the evaporative zone to be recovered as upward vertical flow. As a result, the HELP model may overestimate the deep percolation, particularly in arid climates where such upward flow may be appreciable.

Another limitation of the model, also related to transient gradients, is that capillary barrier effects are not considered. The capillary barrier effect occurs when a coarse textured material underlies a finer grained material. Although the coarse material is considerably more permeable than the fine material under near saturated conditions, the differences in conductivity between the two materials becomes smaller as the materials become drier (capillary pressure increases). Beyond a threshold matric potential, the fine material may be more permeable than the coarse material. As a result, the coarse material acts as a capillary barrier to movement of water until the moisture at the interface builds up sufficiently to drive water into the coarser material. Such effects have the potential to 'hold' water within the root zone until evapotranspiration can remove it and thus reduce the amount of deep percolation through the cover.

The manner in which the HELP model estimates the Brooks-Corey parameters may also lead to problems if appropriate soil parameters are not selected. Computation of the pore-size distribution index based on the field capacity and wilting point water contents typically leads to indices of less than one (the largest value listed for the default soils is 0.651). Brooks and Corey (1964) suggest that a uniform pore size media would have a very large pore-size distribution index (theoretically approaching infinity) while a media with a very wide range of pore sizes would have a very small pore-size distribution index (theoretically approaching zero). They also suggest that for typical porous media, a pore-size distribution index of 2 is usual and that undisturbed, well-aggregated soils sometimes have pore-size distribution indices of less than 1. This implies, then, that the default soils used by the HELP model are agricultural soils with considerable structure (secondary porosity). Because certain key parameters (wilting point water content and pore-size distribution index) are computed by the HELP model based on statistical parameters from the agricultural soil data set and water content data supplied by the user, care should be exercised when user supplied soil properties are input to the model. Therefore, it is best to use soil textural descriptions to select a HELP default soil since these have soil properties which are within the range of observed soil properties which form the basis for the regression equations used in the model.

In spite of the above described limitations, the HELP model apparently provides reasonable estimates of recharge through cover systems. Peyton and Schroeder (1988) compared HELP model results to measured percolation through a liner at a landfill in Kentucky (a humid site) and found that the model overpredicted percolation by about 35%. Other researchers have found that more physically based models tend to predict less percolation than the HELP model. In their study, Stephens and Coons (1994) predicted a long-term percolation rate of 0.0027 in/year for a landfill located in New Mexico where the average annual precipitation is about 8 inches and potential evapotranspiration is about 50 inches per year. They also collected soil cores from undisturbed areas and analyzed the cores for chloride concentration to allow an independent estimate of recharge using the chloride mass balance method described by Allison and Hughes (1978). An average recharge rate of about 0.0075 in/year was computed from the collected data. This compares reasonably well with the estimate from the HELP model.

A.2 UNSAT2 Model

In its most general form, the UNSAT2 variably saturated flow model can be used to evaluate flow in both saturated and unsaturated media. It is a more physically based program than the HELP model and uses the Galerkin finite element method to solve the Richards equation describing flow in a partially saturated media. The model can handle irregularly shaped flow regions as well as nonuniform soils having arbitrary degrees of local anisotropy. Flow can occur in the vertical plane, the horizontal plane, or in a three-dimensional region exhibiting radial symmetry about a vertical axis. Boundary conditions which may be applied include constant head, constant flux and two boundary types which are controlled by atmospheric conditions—the seepage face boundary and the infiltration/evaporation boundary. The model also considers water uptake by plants using a method that accounts for both soil (available water capacity) and atmospheric conditions (potential evapotranspiration). The model is described in detail by Davis and Neuman (1983).

To utilize the model, the flow region must be discretized into quadrilateral or triangular elements. The nodes which form the corners of the elements should be closely spaced in areas where steep gradients are expected but can be more widely spaced in other regions. Soil properties are considered uniform within an element but may vary from element to element. The version of the model used in this study uses the Brooks-Corey parametric equations rather than linear interpolation of tabulated values to compute soil hydraulic properties. Equation 2 is used to compute water content, while relative permeability, K_r, is computed with:

$$K_r = \frac{K}{K_s} = [\frac{\psi_b}{\psi}]^{2+3\lambda} \tag{5}$$

Therefore, the user must supply the porosity, residual water content, bubbling pressure head, pore-size distribution index, and saturated hydraulic conductivity for the two principal directions of anisotropy for each porous medium considered by the model.

Initial conditions must be specified in terms of pressure head or total head throughout the flow region. The model then computes responses to various boundary conditions applied to the modeled area. In this study, the important boundary conditions are the infiltration/evaporation boundary at the surface of the cover and the sink term boundary caused by roots within the evaporative zone. For the surface boundary, the maximum potential surface flux is set for a given time, positive to represent precipitation and negative to represent evaporation. In the case of infiltration, the model first attempts to obtain a solution by setting a constant flux boundary with the flux set equal to the precipitation rate. If the soil cannot transmit the water downward from the boundary, the model sets the pressure at the uppermost nodes to zero and computes the amount of infiltration and the excess precipitation is assumed to become runoff. In the case of an evaporation boundary, a similar approach is utilized in that the model first attempts to obtain a solution by setting the constant flux equal to the potential surface evaporation. If the soil cannot transmit water upward to the surface rapidly enough to meet the demand, the pressure at the soil surface is set to the minimum allowable value specified by the user and the actual rate of evaporation is computed. This approach to computing surface flux is realistic in that the actual value of flux is governed not only by the potential surface flux but also by the ability of the soil to transmit water.

To model water uptake by roots, all elements within the root zone must be rectangular in shape. The first node beneath the soil surface is considered the first root zone node and all nodes in the vertical column to the total rooting depth are considered root zone nodes. At each root zone node, a root effectiveness function must be defined. The model then computes the root uptake based on the root effectiveness function and the capillary pressure within the root zone. If the total uptake, obtained by summing the uptake in each root column, exceeds the potential evapotranspiration, each individual uptake amount is adjusted downward to ensure that the root uptake rate does not exceed the potential evapotranspiration. While this approach is physically based, it is important to note that the user must specify the root effectiveness function which is related to leaf-area index, length of growing season and other plant specific information.

To obtain a solution for any given time, the model computes the distribution of pressure within the flow region at intermediate times. At each time step, an iterative procedure in which a solution is extrapolated from the previous solution as an initial estimate of the solution at the end of the time step is utilized. Iterations continue until an acceptable convergence is obtained. The user can specify the maximum number of iterations attempted in any one time step. Time stepping is controlled by the user who can set the minimum time step, the maximum time step and the time step multiplier. The version of the model utilized in this study includes the capacity to reduce the time step if convergence is not achieved for a second attempt at convergence. During times of wetting front movement (e.g. during a rainstorm), the gradients at the wetting front are sharp and short time steps are required to achieve convergence. Therefore, small time steps are often required at times when boundary conditions change (e.g. on a day when rainfall occurs). The combination of close nodal point spacing, short time steps, and several iterations within a time step leads to the need to perform a large number of computations to evaluate the variations in boundary conditions associated with the performance of a cover.

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RECOMMENDATIONS FOR THE ESTABLISHMENT OF VEGETATION COVER ON OXIDE AND SULFIDE WASTE DUMP SURFACES

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1.0 INTRODUCTION

Work performed by Water, Waste and Land Inc. (1994) has indicated the importance of soil water holding potential and evapotranspiration in reducing percolation rates through waste rock covers. Using the HELP and UNSAT2 models, deep percolation rates through appropriately amended waste rock were predicted to be less than 1 inch per year, and most probably 0.4 inch per year. This calculation is based upon the scenario that an effective vegetation rooting zone of 24" depth is developed within a surface growth medium of significant water holding potential.

1.1 Organic Matter Amendment

From previous studies, performed at Barneys Canyon Mine and elsewhere, empirical evidence exists to prove the value of organic matter additions to mineral soils, including waste rock, in enhancing the water holding capacity of the media. Although Water, Waste and Land Inc has conservatively estimated a 0.5% increase in the organic content of waste rock amended with 10 t/acre organic sludge, recent measurements show that additions of 20 t/acre provide an organic content of up to 5.8%, which is approximately 5.2% more than found in untreated waste rock. Measurements recorded to date indicate that the moisture content of waste rock measured at field capacity, varies almost linearly with organic matter content. Consequently, there is both quantitative and intuitive justification for utilizing organic sludge as a waste rock amendment, to enhance both water holding potential, and vegetation performance.

1.2 Vegetation Cover

While organically amended waste rock is likely to reduce dump infiltration rates significantly, further reductions can be expected to occur as a result of evapotranspiration from a uniform vegetation cover. The evaporative losses from the upper horizon of amended waste rock will vary as a function of rooting depth (the effective evaporation depth) and the surface area of foliage acting as an evapotranspiration surface. The latter is normally quantified as the cumulative surface area of leaf, per unit area of ground. As this leaf area index (LAI) is a cumulative sum, it can exceed 100% ground cover, where 100% cumulative leaf cover is expressed as LAI = 1.

Conservatively, the HELP model simulations have been based on LAI of 1, whereas appropriate management practices could achieve LAI = 1.6, in the Salt Lake area. Therefore, in order to achieve maximum leaf area, thereby enhancing evapotranspiration losses from the vegetated waste rock, a vegetation establishment and management strategy is sought to maximize shoot yield and leaf expansion, whilst controlling root development in accordance with cap design.

1.3 Objectives

This document describes two independent strategies for the establishment of vegetation cover on capped waste rock. As the cover designs differ between oxide and sulfide waste rock, the vegetation strategies necessarily differ. Unlike typical mine waste reclamation schemes, which aim to develop low-yielding but species-rich vegetation on the waste, vegetation cover systems designed to maximize evaporative water loss from the rooting zone aim to maximize yield, at the expense of species diversity, at least in the initial phase of establishment. Consequently, the strategies described below are more agronomic than ecological, and will require some post-establishment maintenance in the short-term. In the longer term, diversification of vegetation cover, particularly by introduction of native tree and shrub species will be appropriate, and will contribute to an increased LAI value.

2.0 OXIDIZED WASTE COVERS

HELP model simulations have indicated that oxidized waste rock amended with organic sludge to a rooting depth of 24" will provide an adequate plant growth medium of significant water holding capacity. In this context, the 24" rooting depth is regarded as typical, but deeper rooting is to be encouraged. On the basis of previous studies, the following generic specifications are appropriate.

2.1 Waste Rock Amendment and Surface Preparation

In order to achieve organic matter incorporation to 24" depth, the surface of the oxidized waste should be ripped to this depth, prior to adding organic material. Fertilizer should also be applied at this point. Once sludge and fertilizer have been applied, the material should be incorporated into the waste by re-ripping or discing horizontal surfaces, and by mixing into slope surfaces using dozer tracks and rippers. The latter assumes a slope angle of ≤2:1.

The following application rates are appropriate:

Sludges	at rates up to 100 t/acre*
18-46-0 fertilizer	310 lb/acre
triple superphosphate	90 lb/acre
*Adjusted for 80% water content to give dry solids application of 20 t/acre; a minimum of 10 t/acre will be required.	

The applications should be performed in spring/early summer, in preparation for seeding in the fall. A period of approximately 3 months will be necessary to allow organic matter mineralization to start, and for volatile ammonia to dissipate from the sludge.

2.2 Species Selection and Seeding

In order to achieve maximum root penetration and leaf area, rapidly, a mixture of fast-growing and high-yielding agricultural grasses and legumes is sought. On the basis of results of reclamation trials recorded to date at Barneys Canyon Mine, the following mixture is recommended for seed drilling; rates should be doubled for hydraulic seeding.

Agropyron smithii (Western wheatgrass var Boston)	6 lb/acre
Agropyron spicatum (Bluebunch wheatgrass var Secar)	6 lb/acre
Secale Agropyron hybrid (Regreen wheatgrass)	10 lb/acre
Medicago sativa (alfalfa var Vernal)	3 lb/acre
Melilotus officinalis (yellow sweet clover var Yukon)	2 lb/acre

The seed mixture is expected to be hydraulically placed, with mulch, in the fall. On slopes, the mixture should include a tackifier. The following application rates are recommended.

silver fiber or alfalfa mulch	2000 lb/acre
plantago gum tackifier	100 lb/acre

The hydraulic application should be performed using the "double application" approach, to ensure an even application of seed and mulch. This is usually performed by spraying the contents of the hydraulic seeder over double the usual area, followed by a second, equal application.

The seed mixture does not contain the full compliment of species, as originally recommended for rock dumps reclamation at Barneys Canyon. In this context, the mixture of agricultural species prescribed above should be regarded as rapidly-growing, high-yielding plants, which are essential to the development of an optimally transpiring ground cover. Recognizing that this strategy provides a crop of relatively low species diversity, a management scheme will be implemented to sequentially diversify the cover, using those native species originally prescribed for waste rock reclamation.

It should be noted, though, that the gradual introduction of native species for ecological stability, rather than agronomic yield, is likely to reduce leaf area available for transpiration, and possible average rooting depth. Therefore, it will be necessary, as a final phase of reclamation, to establish native tree and shrub species onto the cover, thereby increasing LAI and effective rooting depth. It is anticipated that the diversification program will be initiated two years after the establishment of commercial grasses and legumes.

2.3 Maintenance

Given the aim of producing a relatively high-yielding cover crop on the amended waste rock, it is recommended that a topdressing of nitrogen fertilizer is applied to the vegetation, some 6 to 8 weeks after emergence. Nitrogen in the form of urea is the least damaging to foliage, when used as a topdressing, and should be applied at a rate of 45 lb/acre. Future topdressings should be performed on the basis of yield and leaf color.

3.0 SULFIDIC WASTE COVERS

Whilst the development of a functional rooting zone and maximization of leaf area remain important objectives in the reclamation of sulfidic waste rock, a cover design based upon organically amended waste rock alone offers more risk of infiltration and subsequent sulfide oxidation, than more conventional cover designs. The achievement of deep percolation rates of < 0.1"/y, as calculated by the HELP model, will require physical safeguards in addition to an organic reservoir and evapotranspiration zone. Consequently, Water, Waste and Land Inc. recommend a multi-layered system comprising:

- 24" alluvial topsoil or equivalent
- filter blanket
- 12" coarse sand
- 8 - 10" 10^{-8} cms^{-1} clay barrier.

The alluvial topsoil layer is expected to offer a higher water holding capacity than organically amended waste rock. However, the long-term nutritional requirements of the vegetation cover necessitate organic sludge additions to the alluvial topsoil, which is expected to contain a maximum 1% of organic matter, only.

3.1 Topsoil Amendment and Surface Preparation

Given that organic matter in this context is required for long-term nitrogen supply, rather than to enhance water holding capacity, deep incorporation into the topsoil will not be necessary. Furthermore, as root penetration beyond the 24" topsoil layer is undesirable, and should be controlled to prevent breaches of the filter blanket layer, deep phosphate additions should not be attempted. Rather, sludge should be applied alone to a 6" depth, approximately, on pre-ripped topsoil. Pre-ripping should be to a maximum depth of 12", followed by an application of sludge at rates of 40 to 50 t/acre (at 80% water content).

No fertilization will be necessary during the application of sludge, in spring. Rather, applications of 18-46-0 compound will be required in the fall, to be performed at the time of hydraulic seeding.

3.2 Species Selection

A combination of commercial grass and legume species similar to that prescribed for oxidized waste reclamation is appropriate. The mixture should be hydraulically seeded in the fall, at application rates previously described for oxidized waste. The hydraulic seeding and mulching should be performed in two phases, as follows:

- Phase 1. Hydraulic application of fertilizer
  - (18-46-0 compound @ 310 lb/acre)

- Phase 2. Hydraulic seeding and mulching
  - seed @ 54 lb/acre
  - mulch @ 2000 lb/acre
  - tackifier @ 100 lb/acre (on slopes)

3.3 Maintenance

In the interest of promoting of high shoot:root biomass ratio, phosphate additions have been limited, but nitrogen applications should be maintained. Therefore, a spring application of ~~a~~urea should be applied 6 to 8 weeks after emergence. An application rate of 45 lb/acre is recommended, and should be reapplied annually, according to vegetation yield and appearance.

3.4 Root Inhibition

An evaporative zone of 24" is required to reduce infiltration below the rooting layer. Consequently, rapid and extensive root development is required at an early stage in plant growth. However, deep root growth is to be discouraged, in the event of the filter blanket layer being breached. A recommended precaution to avoid this, is the placement of 6 to 12" dolomitic rock above the blanket, upon which the alluvial topsoil will be placed. In so doing, deep penetration of aggressive roots, such as those produced by alfalfa, is likely to be prevented.

Alfalfa roots are unlikely to penetrate a 12" layer of relatively compacted rock. Furthermore, the high magnesium content of dolomitic material is likely to inhibit extensive root growth, beyond the 24" soil layer.

4.0 MONITORING

It is recommended that a 6-monthly monitoring program is implemented to record the development of:

- soil function
- root growth
- leaf area
- shoot yield

Variables of particular importance which should be measured are:

- soil organic matter content
- nitrogen and phosphorus concentrations
- soil moisture tension
- rooting depth
- % vegetation cover
- leaf area index
- shoot yield

In so doing, the constancy of soil organic matter and its effect upon the soil moisture regime can be assessed. Also, the development of shoot and root tissue, with particular reference to root:shoot ratio and leaf area index, should be recorded. In the event of these key variables indicating less than optimal configurations, the soil and vegetation management scheme can be altered accordingly. This type of monitoring program should proceed for a minimum three-year duration.

5.0 LONG-TERM AIM

Ultimately, a self-sustaining and ecologically stable vegetation cover is desirable, whilst retaining those characteristics which are required to maintain an evaporative layer at the dump surface. It is envisaged that the higher yielding grasses and legumes initially established on site will be competitively displaced by native species. Whereas many native grasses and forbs could offer relatively smaller leaf areas, and shallower rooting depths, this potential disadvantage would be offset by systematic introduction of woody species into the dump cover. In particular, the introduction of oak scrub tubelings onto the sulfidic waste dump would provide relatively high leaf area indices, to sustain evapotranspiration, but at relative short rooting depths. Other species to consider in this context include *Cercocarpus ledifolius* (Curlleaf mountain mahogany - oxidized waste) and *Rosa woodsii* (woods rose - sulfidic waste).

It is envisaged, therefore, that a fertilizer maintenance program to maintain high nitrogen and water-demanding agricultural species will be implemented for a two year period, approximately. This schedule is based upon observations of vegetation cover and fertilizer requirements in the existing reclamation trials, at the Barneys Canyon Mine. Thereafter, fertilizer maintenance will be reduced, to promote the natural colonization of native species. The process of native species succession can be accelerated by overseeding with those native species previously recommended for rock dump reclamation. Following successful introduction of native ground cover, a tree/shrub transplantation program would commence.

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Mine Permit Number M0350009 Mine Name Barneys Canyon
Operator Kennecott Barneys CYN Date 8-5-1994
TO ______ FROM ______

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__MULTIPUL DOCUMENT TRACKING SHEET __NEW APPROVED NOI
__AMENDMENT _OTHER______

Description YEAR-Record Number

__NOI X Incoming __Outgoing __Internal __Superceded

Waste Rock Management Plan

__NOI __Incoming __Outgoing __Internal __Superceded

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